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• Shirato, Tadashi
Kiyose-shi, Tokyo 204 (JP)

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(74) Representative: Skone James, Robert Edmund
GILL JENNINGS & EVERY
Broadgate House
7 Eldon Street
London EC2M 7LH (GB)

(71) Applicant: **NIPPON TELEGRAPH AND
TELEPHONE CORPORATION**
Shinjuku-ku, Tokyo 163-19 (JP)

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(72) Inventors:
• Takao, Toshiaki
Yokohama-shi, Kanagawa 236 (JP)
• Suzuki, Yoshifumi
Yokosuka-shi, Kanagawa 238-03 (JP)

(54) Clock timing recovery methods and circuits

(57) In a clock timing recovery circuit for recovering the clock timing from a baseband signal obtained by detection of a received signal, clock timing is rapidly established by using a clock which has been phase-shifted from the desired clock timing to sample the baseband

signal, and by obtaining the optimum phase from the sampled signal obtained as a result. A clock-timing recovery circuit according to this invention does not require oversampling and provides easy optimisation of circuit constants.

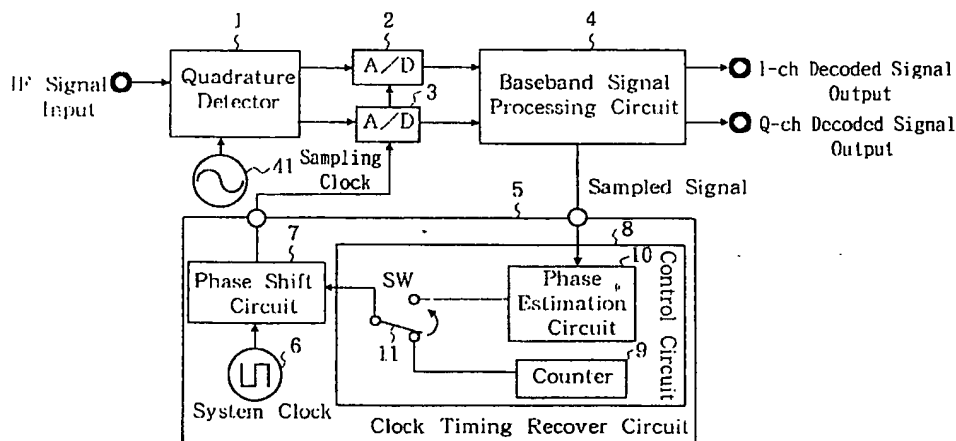


FIG.4

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Description

The present invention relates to the transmission of digital data and in particular to the recovery of clock timing at the receiving side.

5 Some terminology used in this specification will be defined. First of all, "sampling clock" means a clock used for sampling in a demodulator. Next, "clock timing" means the timing of the sampling clock when the bit error rate is minimum. Finally, "symbol rate" means the rate at which the main signal changes, i.e., the modulation rate.

The growth of multimedia communications in recent years has necessitated the provision of multimedia wireless communication systems capable of high-speed transmission of digital data in burst form. Examples of such systems 10 include high-speed wireless local area networks (LANs) and future public land mobile telecommunication. To process digital data at high speeds without bit errors, it is essential to have, at the receiving side of these wireless communication systems, a clock timing recovery circuit which rapidly establishes the clock timing using a signal for clock timing recovery added to the front of a burst of digital data, and which subsequently tracks fluctuations in clock timing. A clock timing recovery circuit which tracks fluctuations in clock timing is also necessary when transmitting continuous digital data.

15 Conventional clock timing recovery circuits can be broadly divided into circuits which recover clock timing at the symbol rate by analogue processing, and circuits which recover clock timing by digital processing after oversampling. A tank-limiter clock recovery circuit using IF signal operation is an example of the former, while a clock recovery circuit using a binary quantized digital phase-locked loop (BQDPL) is an example of the latter. Examples of the configuration of these two conventional kinds of clock timing recovery circuit are explained below.

20 FIG. 1 shows an example of the configuration of a demodulator provided with a tank-limiter clock recovery circuit using IF signal operation. This demodulator comprises quadrature detector 1 to which the IF signal is input, analogue-to-digital converters 2 and 3 which sample the outputs of quadrature detector 1, baseband signal processing circuit 4 which obtains decoded signals by processing the sampled signals that are output by analogue-to-digital converters 2 and 3, and tank-limiter clock recovery circuit using IF signal operation 200 for recovering the clock timing. Tank-limiter 25 clock recovery circuit using IF signal operation 200 comprises envelope detection circuit 201, tank circuit 202 and limiter circuit 203.

The IF signal is input to envelope detection circuit 201, which extracts the clock frequency component by nonlinear processing of the IF signal, which does not itself contain the clock frequency component. Tank circuit 202 comprises 30 a narrowband band-pass filter and reduces clock jitter. Limiter circuit 203 shapes the sinusoidal clock obtained by tank circuit 202 into a square wave. If sampling is performed using the clock obtained in this way, the bit error rate is minimised. It is this clock which is supplied to various sections of the demodulator, including analogue-to-digital converters 2 and 3.

A detailed explanation of a tank-limiter clock recovery circuit using IF signal operation is given in "TDMA Communications" by Yamamoto and Kato, published by the IEICE Japan.

35 FIG. 2 shows an example of the configuration of a demodulator provided with a clock recovery circuit using a binary quantised digital phase-locked loop (BQDPL). A flowchart of the operation of this BQDPL clock recovery circuit is given in FIG. 3. The demodulator comprises quadrature detector 1 to which the IF signal is input, analogue-to-digital converters 2 and 3 which sample the output of quadrature detector 1, baseband signal processing circuit 4 which obtains demodulated signals by processing the sampled signals that are output by analogue-to-digital converters 2 and 3, and 40 BQDPL clock recovery circuit 210 which recovers the clock timing. BQDPL clock recovery circuit 210 comprises zero-crossing detector 211, phase decision circuit 212, loop filter 213, and VCO (voltage-controlled oscillator) 214.

Analogue-to-digital converters 2 and 3 and baseband signal processing circuit 4 operate at twice the symbol rate, and input to BQDPL clock recovery circuit 210 the sampled signal obtained by sampling at twice the symbol rate. Sampled signal $D(t+nT)$, which has the same period as the symbols, is input to zero-crossing detector 211. (T is the 45 symbol period and n is an arbitrary integer.) When the sign of the input signal inverts (i.e., when a zero-crossing occurs) zero-crossing detector 211 sends notification of this to phase decision circuit 212. Sampled signal $D(t+nT)$ is then input to phase decision circuit 212 along with sampled signal $D\{t+(n-1/2)T\}$ which has been sampled with a timing leading $D(t+nT)$ by $T/2$. Phase decision circuit 212 decides, on the basis of the signs of the two signals, whether the sampling timing leads or lags the clock timing (at which the bit error rate is minimum). In other words, if $D(t+nT) \times D\{t+(n-1/2)T\}$ is positive, it decides that the sampling timing lags, and if it is negative, it decides that it leads. Phase decision circuit 50 212 outputs a decision result only when zero crossing detector 211 has detected a zero crossing. Loop filter 213 is a type of integrating circuit and integrates the decision results of phase decision circuit 211, and on the basis of the result of this integration controls the frequency of the clock (twice the symbol rate) output by VCO 214. The result of this processing is that any lead or lag of the sampling timing is regulated and a clock timing giving a minimum bit error rate is obtained. It is this clock which is supplied to various sections of the demodulator, including analogue-to-digital converters 2 and 3. 55

A detailed explanation of a BQDPL clock recovery circuit is given in "Digital Communications By Satellite" by V.K. Bhargava, D. Haccoun, R. Matyas and P.P. Nuspi, New York: Wiley, 1981.

Tank-limiter clock recovery circuits using IF signal operation and BQDPL clock recovery circuits are both widely employed in the receivers used when low-speed digital data is being transmitted. However, several problems are encountered in receiving high-speed digital data. These problems will be explained below.

A tank-limiter clock recovery circuit using IF signal operation employs a tank circuit, which is a narrowband band-pass filter, to reduce clock jitter. To reduce clock jitter, the Q of the tank circuit has to be made large ($Q = f_0/\Delta f$, where f_0 is the centre frequency of the filter and Δf is the 3-dB bandwidth). However, the delay of a single-tuned resonator, which is generally used as a tank circuit, can be expressed as approximately Q/4 (symbols). Accordingly, if the Q is made large, the delay of the tank circuit is lengthened, with the result that more time is needed to recover the clock timing. By way of an example, in a wireless LAN system conforming to RCR standard STD-34A, "19GHz Band Data Transmission Radio Equipment for Premises Radio Station", established by the Research & Development Centre for Radio Systems, the Q required to obtain a good bit error rate is around 110. In this case, the delay is approximately 28 symbols which means that a considerable time is needed to recover the clock timing. Moreover, because this circuit is an analogue circuit, it is difficult to reduce clock jitter and to optimise the time taken to recover the clock timing. A further shortcoming is that because the clock frequency component has been removed from the IF signal, the clock is lost if the level of the IF signal drops as a result of fluctuations etc. of the propagation path conditions.

The loop filter of a BQDPL clock recovery circuit integrates a control signal that shows the phase lead or lag of the sampling clock. In other words, the VCO is controlled after the signal for clock timing recovery has been observed for a long time. Clock jitter can therefore be reduced by increasing the integration time of the loop filter, but because this also results in more time being required to recover the clock timing, there is the same problem as encountered with a tank-limiter clock recovery circuit using IF signal operation. Furthermore, more time is required to correct the phase difference between the initial phase of the clock which is output by the VCO and the phase of the clock timing which minimises the bit error rate, as this phase difference becomes larger. A resulting problem is that under normal service conditions, in which the size of the phase difference is not fixed, there will be a spread in the time taken to recover the clock timing. Moreover, because this circuit requires oversampling at twice or more times the symbol rate, there are difficulties involved in digital implementation and in coping with increases in the transmission rate of digital data.

It is an object of the present invention to provide a clock timing recovery method and circuit which overcomes such problems, can rapidly establish the clock timing, does not require oversampling, and wherein circuit constants are readily optimised.

According to a first aspect of the present invention, there is provided a clock timing recovery circuit comprising clock generating means which generates a system clock which repeats with a fixed period, phase shift means which outputs a first clock, which is phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal, and control means for controlling the amount of phase shift of this phase shift means; wherein a signal for clock timing recovery is added to the baseband signal; and the control means includes first means which causes there to be output from the phase shift means, as a sampling clock for sampling the signal for clock timing recovery, a first clock whereof the phase of its n-th leading edge point or trailing edge point ($n = 1, 2, 3, \dots$) from the origin, where one leading edge point or trailing edge point of the system clock is taken as the origin, is shifted by $n \times \Delta t$ relative to the phase of the system clock (where Δt is a predefined amount of phase shift); and second means which estimates, from the sampled signal obtained by sampling the signal for clock timing recovery, the phase difference between the phase of the system clock and the clock timing at which the bit error rate becomes minimum, and which, on the basis of this estimated phase difference, causes there to be output from the phase shift means the clock timing for sampling the baseband signal that follows the signal for clock timing recovery.

Radio communication equipment for transmitting digital data in bursts generally transmits and receives burst signals comprising a signal for clock timing recovery (BTR), a signal for frame synchronisation (UW), and data. The BTR portion of the baseband signal obtained by receiving and detecting this burst signal approximates to a sine wave (in the absence of noise and transmission path distortion it is an exact sine wave), and the rest of the signal will form an eye pattern. The first aspect of this invention utilises the fact that the BTR portion of the baseband signal approximates a sine wave, and after sampling this signal with a successively phase-shifted clock, uses the sampled signal obtained to estimate the clock timing. This enables clock timing to be recovered rapidly in a time period of the order of four symbols.

In order to make the clock timing recovered from the BTR portion track frequency fluctuations of clock timing in other portions of the baseband signal, there can be provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock that is output by the phase shift means by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of this first clock by the same timing difference δt ; and means which selects the clock which the control means, using the first means, makes the phase shift means output as the sampling clock for sampling the signal for clock timing recovery, and which selects the output of the sampling clock generating means as the sampling clock for sampling the baseband signal that follows the signal for clock timing

recovery; and the second means can include arithmetic means which calculates the amount of phase shift of the phase shift means by comparing the decision error obtained from the sampled signal at the leading or trailing edge points that lead by δt , with the decision error obtained from the sampled signal at the leading or trailing edge points that lag by δt .

By tracking frequency fluctuations, accurate clock timing recovery can be performed and bit errors of digital data can be reduced even when a system clock with poor frequency stability is used.

The configuration that serves to track frequency fluctuations can also be utilised independently of the configuration of the first aspect of this invention.

According to a second aspect of the present invention, there is provided a clock timing recovery circuit comprising clock generating means which generates a system clock which repeats with a fixed period, phase shift means which outputs a first clock, which is phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal, and control means for controlling the amount of phase shift of this phase shift means; wherein there is provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; and wherein the control means includes arithmetic means which calculates the amount of phase shift of the phase shift means by comparing information relating to the phase error of the clock timing, said information being obtained respectively from the sampled signals obtained by sampling the baseband signal using the second and third clocks as the respective sampling clocks.

The decision error of the phase component of the sampled signal obtained by sampling can be utilised as the information relating to the phase error. Alternatively, when the baseband signal is obtained by coherent detection, the decision error of the signal points of the sampled signal can be utilised. By utilising the decision error of the phase component or the decision error of the signal points, not only can clock timing be recovered for portions of the burst signal other than the BTR, but it will also be possible to recovery clock timing from a continuous signal.

It is also possible to utilise the amplitude of the sampled signal obtained by sampling the BTR as the information relating to phase error that is used to recover the clock timing from the BTR. In this case, it is preferable to provide a means which shifts the timing of the first clock by a half period when it has been detected from the signal for clock timing recovery that the timing of the system clock and the clock timing of the baseband signal deviate by a half period.

A possible configuration is for the sampling clock generating means to include means which alternately selects the second clock and the third clock and outputs these as one clock, and for the control means to compare the phase error related information obtained alternately in respect of the second clock and the third clock. A possible configuration different from this is for the sampling clock generating means to output the second clock and the third clock separately, and for the control means to compare the phase error related information obtained separately in respect of the second clock and the third clock. When the second clock and the third clock are output separately, a possible configuration is for the second clock to be output as a sampling clock for one of the in-phase channel and the quadrature channel; for the third clock to be output as a sampling clock for the other channel, and for the arithmetic means to compare the phase error related information obtained respectively from the in-phase channel and the quadrature channel.

A possible configuration is for the second and third clocks generated by the sampling clock generating means to be output to the main signal lines as sampling clocks for decoding the digital data from the baseband signal. A possible configuration different from this is to output the first clock to the main signal lines as the sampling clock for decoding the digital data from the baseband signal, and to provide sampling means which uses the second clock and the third clock to sample the baseband signal in separate lines from the main signal lines, and means for obtaining phase error related information from the output of this sampling means.

When recovering clock timing from a burst signal, it is also possible to acquire the clock by utilising the amplitude of the sampled signal obtained by sampling the BTR, and to track frequency fluctuations of clock timing by utilising the decision error of the sampled signal obtained by sampling a portion of the signal other than the BTR.

Namely, according to a third aspect of the present invention, there is provided a clock timing recovery circuit comprising clock generating means which generates a system clock which repeats with a fixed period, phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal, and control means for controlling the amount of phase shift of this phase shift means; wherein a signal for clock timing recovery is added to the baseband signal; and wherein there is provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; and wherein the control means includes first arithmetic means which calculates the amount of phase shift of the phase shift means by comparing the amplitudes of the sampled signals respectively obtained by sampling the signal for clock timing recovery using the second and third clocks respectively as sampling clocks, and second arithmetic means which calculates the amount of phase shift of the phase shift means by comparing the decision errors obtained when the baseband signal following the signal for clock timing recovery is sampled using the second and

third clocks respectively as sampling clocks.

According to a fourth aspect of the present invention, there is provided a clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband signal obtained by detection of the received signal, the clock timing for sampling the baseband signal that follows this signal for clock timing recovery, said method comprising forming, as the sampling clock, a clock whereof the phase of its n -th leading edge point or trailing edge point ($n = 1, 2, 3, \dots$) from the origin, where one leading edge point or trailing edge point of a system clock which repeats with a fixed period is taken as the origin, is shifted by $n \times \Delta t$ relative to the phase of the system clock (where Δt is a predefined amount of phase shift); sampling the signal for clock timing recovery using this sampling clock; estimating, from the sampled signal obtained by this sampling, the phase difference between the phase of the system clock and the clock timing at which the bit error rate is minimum; and recovering the clock timing for sampling the baseband signal that follows the signal for clock timing recovery by causing the phase of the system clock to shift by the estimated amount of phase difference.

According to a fifth aspect of the present invention, there is provided a clock timing recovery method for recovering clock timing on the basis of the decision error of the sampled signal obtained by sampling the baseband signal, said method comprising forming, from a first clock obtained by phase shifting a system clock which repeats with a fixed period, a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , said second and third clocks serving as sampling clocks for the main signal lines; obtaining decision errors from the sampled signals obtained by using these second and third sampling clocks to sample the baseband signal; calculating the amount of phase shift to be applied to the first clock on the basis of the result of comparing the decision error obtained from the sampled signal at the leading edge or trailing edge point of the second clock with the decision error obtained from the sampled signal at the leading edge or trailing edge point of the third clock; and shifting the phase of the system clock on the basis of this calculated amount of phase shift.

According to a sixth aspect of the present invention, there is provided a clock timing recovery method for recovering clock timing on the basis of the decision error of the sampled signal obtained by sampling the baseband signal, said method comprising: outputting, as the sampling clock for the main signal lines, a first clock obtained by phase shifting a system clock which repeats with a fixed period, and forming a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; obtaining decision errors from the sampled signals obtained using these second and third clocks to sample the baseband signal separately from the main signal lines; calculating the amount of phase shift to be applied to the first clock on the basis of the result of comparing the decision error obtained from the sampled signal at the leading edge or trailing edge point of the second clock, with the decision error obtained from the sampled signal at the leading edge or trailing edge point of the third clock; and shifting the phase of the system clock on the basis of this calculated amount of phase shift.

According to a seventh aspect of the present invention, there is provided a clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband signal obtained by detection of the received signal, the clock timing required for decoding this baseband signal, said method comprising: forming, from a first clock obtained by phase shifting a system clock which repeats with a fixed period, a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , these second and third clocks serving as sampling clocks for the main signal lines; using these sampling clocks to sample the signal for clock timing recovery; comparing, in respect of the sampled signals obtained by this sampling, the amplitude of the sampled signal at the leading edge point or trailing edge point of the second clock with the amplitude of the sampled signal at the leading edge point or trailing edge point of the third clock; calculating the amount of phase shift to be applied to the first clock on the basis of the result of this comparison; and recovering the clock timing by shifting the phase of the system clock on the basis of this amount of phase shift.

According to an eighth aspect of the present invention, there is provided a clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband signal obtained by detection of the received signal, the clock timing required for decoding this baseband signal, said method comprising: outputting, as the sampling clock for the main signal lines, a first clock obtained by phase shifting a system clock which repeats with a fixed period, and forming a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; using these second and third clocks to sample the signal for clock timing recovery in separate lines from the main signal lines; comparing, in respect of the sampled signals obtained by this sampling, the amplitude of the sampled signal at a leading edge point or a trailing edge point of the second clock with the amplitude of the sampled signal at the leading edge point or trailing edge point of the third clock; and recovering the clock timing by shifting the phase of the system clock on the basis of this amount of phase shift.

of the third clock; calculating the amount of phase shift to be applied to the first clock on the basis of the results of this comparison; and recovering the clock timing by shifting the phase of the system clock on the basis of this amount of phase shift.

5 In the fifth to the eighth aspects, the baseband signal can be sampled by means of a clock obtained by alternately selecting the second clock and the third clock, or by sampling the baseband signal separately using the second clock and the third clock. When separate sampling is performed, the signal in the in-phase channel can be sampled using one clock and the signal in the quadrature channel can be sampled using the other clock.

10 In the seventh and eighth aspects, the timing of the first clock can be shifted by a half period when it has been detected from the signal for clock timing recovery that the timing of the system clock and the clock timing of the received signal deviate by a half period.

Brief Explanation of the Drawings

15 FIG. 1 is a block diagram showing a prior art example of the configuration of a demodulator provided with a tank-limiter clock recovery circuit using IF signal operation.

FIG. 2 is a block diagram showing a prior art example of the configuration of a demodulator provided with a BQDPL clock recovery circuit.

FIG. 3 is a flowchart showing the operation of the BQDPL clock recovery circuit illustrated in FIG. 2.

FIG. 4 is a block diagram showing a first embodiment of the present invention.

20 FIG. 5 shows the flow of the control of amount of phase shift in the first embodiment.

FIG. 6(a)-(f) serve to explain the operation of the clock timing recovery circuit of the first embodiment.

FIG. 7 shows an example of the detailed configuration of a phase estimation circuit.

FIG. 8(a)-(f) serve to explain an example of the operation of the clock timing recovery circuit.

FIG. 9 shows an example of the configuration of a phase shift circuit.

25 FIG. 10(a)-(g) serve to explain another example of the operation of the clock timing recovery circuit.

FIG. 11 is a block diagram showing a second embodiment of the present invention.

FIG. 12 shows the decision error as a function of sampling timing in the baseband signal processing circuit.

FIG. 13(a)-(g) show the various signal waveforms.

FIG. 14 serves to explain the operating principles.

30 FIG. 15 is a block diagram showing a third embodiment of the present invention.

FIG. 16 shows the operating flow of the third embodiment.

FIG. 17 shows an example of a specific configuration of a sampling clock generator.

FIG. 18 shows an example of the configuration of a phase control circuit.

FIG. 19 shows another example of the configuration of a sampling clock generator.

35 FIG. 20 shows the sampling clock which is output by the sampling clock generator illustrated in FIG. 19.

FIG. 21 is a block diagram showing a fourth embodiment of the present invention.

FIG. 22 is a block diagram showing a fifth embodiment of the present invention.

FIG. 23 shows an example of the configuration of a phase control circuit.

FIG. 24 is a block diagram showing a sixth embodiment of the present invention.

40 FIG. 25 shows an example of the configuration of a phase control circuit.

FIG. 26 is a block diagram showing a seventh embodiment of the present invention.

FIG. 27 is a block diagram showing an eighth embodiment of the present invention.

FIG. 28 is a block diagram showing a ninth embodiment of the present invention.

FIG. 29 shows the operation flow of the ninth embodiment.

45 FIG. 30(a)-(j) show the timing of the various signals.

FIG. 31 shows the relation between the sampling timing and the square of the sampled signal.

FIG. 32 serves to explain operation in the pseudostable state.

FIG. 33 is a block diagram showing a tenth embodiment of the present invention.

FIG. 34 shows an example of the configuration of the phase control circuit in the tenth embodiment.

50 FIG. 35 is a block diagram showing an eleventh embodiment of the present invention.

FIG. 36 shows an example of the configuration of the phase control circuit in the eleventh embodiment.

FIG. 37 is a block diagram showing a twelfth embodiment of the present invention.

FIG. 38 is a block diagram showing a thirteenth embodiment of the present invention.

55 FIG. 39 is a block diagram showing an example in which a circuit for coping with the pseudostable state has been provided in the clock timing recovery circuit of the tenth embodiment.

FIG. 40 is a block diagram showing an example of a kick-off circuit.

FIG. 41 is a block diagram showing another example of a kick-off circuit.

FIG. 42(a)-(h) show the timing of the various signals in the pseudostable state.

Embodiments of the Invention

FIG.4 is a block diagram showing a first embodiment of the present invention, and shows the configuration of a demodulator equipped with a clock timing recovery circuit. This particular embodiment rapidly recovers the clock timing using only a signal for clock timing recovery that has been added to the burst signal frame.

This demodulator comprises quadrature detector 1 to which the IF signal is input, oscillator 41 which generates a carrier signal which is not synchronized with the IF signal and supplies this to quadrature detector 1, analogue-to-digital converters 2 and 3 which convert the in-phase and quadrature outputs of quadrature detector 1 to digital signals, baseband signal processing circuit 4 which processes the digital signals output by analogue-to-digital converters 2 and 3, and clock timing recovery circuit 5 which recovers, from the clock timing recovery signal, the clock timing for demodulating the received signal.

Clock timing recovery circuit 5 comprises system clock generator 6 for generating a system clock that repeats with a fixed period, phase shift circuit 7 which outputs a first clock, phase shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal, and control circuit 8 for controlling the amount of phase shift of phase shift circuit 7.

Control circuit 8 comprises counter 9, phase estimation circuit 10, and switch 11 which selects one of the output of counter 9 and the output of phase estimation circuit 10. Counter 9 outputs a phase control signal synchronised with the system clock, and causes there to be output from phase shift circuit 7, as a sampling clock for sampling the clock timing recovery signal, a clock whereof the phase of its n -th leading edge point or trailing edge point ($n = 1, 2, 3, \dots$) from the origin, where one leading edge point or trailing edge point of the system clock is taken as the origin, is shifted by $n \times \Delta t$ relative to the phase of the system clock (where Δt is a predefined amount of phase shift). Phase estimation circuit 10 estimates, from the sampled signal obtained by sampling the clock timing recovery signal, i.e., from the sampled signal from baseband signal processing circuit 4, the phase difference between the phase of the system clock and the clock timing at which the bit error rate is minimum, and on the basis of this estimated phase difference causes there to be output from phase shift circuit 7 the clock timing for sampling the baseband signal that follows the clock timing recovery signal. Switch 11 selects the output of counter 9 with the timing of the clock timing recovery signal, and at other times selects the output of phase estimation circuit 10, and supplies these outputs to phase shift circuit 7. The flow of the control of amount of phase shift by control circuit 8 is shown in FIG.5.

FIG.6(a)-(f), which serve to explain the operation of the clock timing recovery circuit of the first embodiment, shows the following: FIG.6(a) format of the burst signal input to quadrature detector 1 as the intermediate frequency signal; FIG.6(b) baseband signal output from quadrature detector 1; FIG.6(c) desired clock timing; FIG.6(d) system clock output by system clock generator 6; FIG.6(e) sampling clock output from phase shift circuit 7; FIG.6(f) sampled signal supplied to clock timing recovery circuit 5 from baseband signal processing circuit 4.

A code for efficiently recovering the clock timing is generally added to the front of a burst signal. For example, in the case of QPSK modulation, a bit pattern comprising repetitions of "1100" or "1001" is added. The clock timing recovery signal (BTR) obtained after limiting the bandwidth of this code is the sine wave of period $2T$ shown in FIG.6 (b), where T is the symbol period. This signal is sampled by analogue-to-digital converters 2 and 3. The sampling clock used (see FIG.6(e)) is the clock obtained as a result of phase shift circuit 7 having caused the period of the system clock (see FIG.6(d)) generated by system clock generator 6, said system clock having the same clock speed as the symbol rate, to change by a fixed amount Δt at each sample. The sampled signal obtained by sampling (see FIG.6(f)) is input to phase estimation circuit 10. Phase estimation circuit 10 estimates, on the basis of this sampled signal, the phase difference between the system clock and the timing at which the clock timing recovery signal exhibits an extreme value, i.e., the mid-point of a symbol. The estimation result is output to phase shift circuit 7 which shifts the phase of the system clock by the estimated phase difference, thereby establishing the phase of the sampling clock (see FIG.6(c)).

After the phase of the sampling clock has been established, the sampling clock is held constant until the end of the burst signal by keeping the amount of phase shift of phase shift circuit 7 constant. Alternatively, the phase of the sampling clock is finely adjusted by making minute changes to the amount of phase shift under control of phase estimation circuit 10.

Thus, according to this embodiment, the phase of the sampling clock can be aligned with the mid-point of the symbols by processing at about the symbol rate. This is the alignment at which the eye pattern opening is largest, and results in the clock timing at which the bit error rate is minimum. In other words, the clock timing at which the bit error rate is minimum can be recovered.

FIG.7 is a block diagram showing an example of the detailed configuration of phase estimation circuit 10. This phase estimation circuit 10 comprises multipliers 12 and 13 which respectively square the sampled signals in the in-phase and quadrature channels (hereinafter expressed as "I-ch" and "Q-ch"), adder 14 which adds the outputs of these, counter 15 which counts the number of samples by observing when the digital data representing a sampled signal changes, a plurality of delay circuits 16 which successively delay the output of adder 14 by delay time $T' (= T + \Delta t)$, and ROM 17 in which an estimate of the phase difference between the system clock and the clock timing at which the bit

error rate is minimum has been stored in advance.

In FIG.8(a)-(f), which serves to explain an example of the operation of this phase estimation circuit 10, the following waveforms are shown: FIG.8(a) baseband signal, FIG.8(b) output of adder 14, FIG.8(c) system clock, FIG.8(d) sampling clock, FIG.8(e) square of sampled signal, FIG.8(f) sampling clock after the phase has been established.

5 Phase estimation circuit 10 shown in FIG.7 uses multipliers 12 and 13 and adder 14 to calculate $(I-\text{ch})^2 + (Q-\text{ch})^2$, so as to eliminate carrier phase error induced amplitude fluctuations of the sampled signal. An alternative configuration is to perform this calculation by analogue means prior to sampling and to sample the resulting signal by means of analogue-to-digital converters separate from the main signal lines.

10 The sampled signal obtained is successively delayed by $T' (= T + \Delta t)$ by a plurality of delay circuits 16 (where T' is the sampling clock period) and input to ROM 17. Counter 15 observes the data changes of the sampled signal and thereby counts the number of samplings, which it inputs to ROM 17.

ROM 17 estimates, from the number of samplings and a plurality of sampled signals, the phase difference between the system clock and the clock timing at which the bit error rate becomes minimum, and outputs this as a phase difference estimation result. By way of example, the estimation of phase difference can be performed as follows.

15 By phase shifting the system clock by Δt at every sampling, a sampling clock giving a sampling interval which has been changed by a fixed quantity can be obtained. If the result of the calculation of $(I-\text{ch})^2 + (Q-\text{ch})^2$ is sampled with the sampling clock thereby obtained, the n -th sampled signal works out as:

$$20 \quad Y_n = A^2 \{1 + \cos(\omega_c n \Delta t - \phi)\} \quad (1)$$

where, A is the amplitude, ω_c is the angular frequency of the system clock, Δt is the amount of phase shift, and ϕ is the phase difference between the system clock and the clock timing at which the bit error rate is smallest. ϕ can be expressed as follows:

$$25 \quad \phi = \cos^{-1} \frac{Y_{n-1} F(n) + Y_{n+1} F(n-1) - 2Y_n \cos(\omega_c n \Delta t)}{2Y_n \cos(\omega_c \Delta t) - (Y_{n-1} + Y_{n+1})}$$

$$30 \quad F(n) = \frac{\sin\{\omega_c (n+1)\Delta t\} - \sin(\omega_c n \Delta t)}{\sin(\omega_c n \Delta t)} \quad (2)$$

35 The value of ϕ obtained from Equation 2 is stored in ROM 17. Equation 2 is merely one example, and alternatively the \sin^{-1} or \tan^{-1} function can be utilised. The phase difference ϕ can be estimated from Equation 2 using the three lowest sampled signals. The clock timing can therefore be recovered in a short space of time.

In the foregoing example, a ROM was used to estimate phase difference ϕ , but it is also possible to perform a similar calculation with a combination of multipliers and adders. Another possibility would be to use a microprocessor or digital signal processor and perform the calculation using software.

40 The operation of the circuits shown in FIG.4 and FIG.7 will now be explained again in terms of the notation used in the above equations. Counter 9 outputs a phase control signal $\theta = n\omega_c \Delta t$ ($n = 0, 1, 2, \dots$) synchronised with the system clock. Switch 11 outputs the phase control signal from counter 9 to phase shift circuit 7 until it obtains the value of phase difference ϕ from ROM 17 in phase estimation circuit 10. When the value of the phase difference ϕ has been obtained from ROM 17, θ is set to $-\phi$ and is output to phase shift circuit 7. Phase shift circuit 7 shifts the phase of the system clock output from system clock generator 6 by θ , the value of the phase control signal, and outputs a sampling clock which has established the phase. As a result, the clock timing at which the bit error rate is minimum can be recovered.

45 FIG.9 shows an example of the configuration of phase shift circuit 7. This phase shift circuit 7 comprises ROMs 21 and 22, digital-to-analogue converters 23 and 24, hybrids 25 and 28, and analogue multipliers 26 and 27. Phase control signal θ and the system clock are input to this phase shift circuit 7. ROMs 21 and 22 respectively output the values of $\cos\theta$ and $\sin\theta$ for input phase control signal θ . Digital-to-analogue converters 23 and 24 respectively convert these values to analogue signals and output these to analogue multipliers 26 and 27. Hybrid 25 splits the input system clock into two clocks with a 90° phase difference between them, and outputs these to analogue multipliers 26 and 27. Analogue multipliers 26 and 27 multiply the two clocks split by hybrid 25 by the values of $\cos\theta$ and $\sin\theta$ respectively, and hybrid 28 adds the results of these multiplications. The result of this processing is that a sampling clock phase-shifted from the system clock by θ is obtained.

55 In the example configuration shown in FIG.9, the phase shift circuit comprised analogue circuits, but it is also possible for it to comprise digital circuits entirely. This can be achieved by using a clock generator to generate a clock

at M times the system clock (where M is determined by the step width of the phase shift) and a variable-length register to give a variable amount of shift.

In the foregoing explanation, the $(I\text{-ch})^2 + (Q\text{-ch})^2$ form of the sampled signal was represented by Equation 1. On the other hand, when coherent detection is employed for the demodulation, because the influence of carrier phase error can be virtually ignored, the $(I\text{-ch})^2$ or $(Q\text{-ch})^2$ form of the sampled signal can be represented by Equation 1. It is also possible to estimate phase difference ϕ by expressing the I-ch or Q-ch form of the sampled signal as:

$$Y_n = A \cos(\omega_c n \Delta t/2 - \phi) \quad (3)$$

If a clock recovery code is transmitted from the transmitting side as a binary signal, it will also be possible to utilise the clock timing recovery circuit of the embodiment described above for a multilevel modulation scheme.

Furthermore, if the modulation scheme is $\pi/4$ shift QPSK, because the carrier phase plane rotates in a fixed direction by $\pi/4$ at every symbol, baseband signal processing circuit 4 corrects the carrier phase plane by $-\pi/4$ at every symbol. This correction can also be performed on an analogue basis prior to analogue-to-digital converters 2 and 3.

In the foregoing explanation of the first embodiment, it was assumed that the demodulator employs coherent detection, quasi-coherent detection or baseband delay detection schemes, and that the clock timing recovery circuit is capable of supporting these schemes. However, the clock timing recovery circuit described above can also be utilised in similar manner in a demodulator that uses an IF delay detection scheme.

FIG.10(a)-(g) serve to explain another example of the operation of clock timing recovery circuit 5, and shows an example in which the sampled signal is approximated not by a trigonometric function but by an Nth order polynomial. The following waveforms are shown: FIG.10(a) baseband signal, FIG.10(b) $(I\text{-ch})^2 + (Q\text{-ch})^2$, FIG.10(c) system clock, FIG.10(d) sampling clock, FIG.10(e) sampled signal, FIG.10(f) sampling clock after the phase has been established, FIG.10(g) sampling clock with phase inverted.

In this case, N+1 sampled signals obtained in the same manner as explained with reference to FIG.8(a)-(f) are approximated by an Nth order polynomial. Namely:

$$y(t) = a_0 + a_1 t + \dots + a_N t^N \quad (4)$$

The values of a_n in this equation ($n = 1, 2, \dots, N$) are found. To do this, if simultaneous equations with N+1 unknowns are solved, the following equation is obtained:

$$\begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_N \end{bmatrix} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 1 & \Delta t & \dots & \Delta t^N \\ \vdots & \vdots & \ddots & \vdots \\ 1 & N\Delta t & \dots & (N\Delta t)^N \end{bmatrix}^{-1} \begin{bmatrix} y(0) \\ y(\Delta t) \\ \vdots \\ y(N\Delta t) \end{bmatrix} \quad \dots\dots\dots(5)$$

Next, to obtain the extreme values of Equation 4, t is found after differentiating Equation 4, which gives:

$$dy/dt = a_1 + 2 a_2 t + \dots + n a_N t^{N-1} \quad (6)$$

In addition, when $n\Delta t \equiv t$, if the value of the nth sampled signal $y(n\Delta t)$ approaches a maximum value of the sampled signal, then because t is a maximum point, the phase shift circuit is controlled by the clock timing estimation circuit so that sampling takes place with timing t. Conversely, if $y(n\Delta t)$ approaches a minimum value, then because t is a minimum point, the phase shift circuit is controlled by the clock timing estimation circuit so that after the sampling clock has been established with timing t, the phase of this timing is inverted. This gives the clock timing at which the bit error rate is minimum.

According to the embodiment explained above, it is unnecessary to oversample as in a conventional clock recovery

circuit using a binary quantised digital phase-locked loop, and because processing can be performed using a sampling clock of the same order as the symbol rate, the circuit can easily cope with high transmission rates. Moreover, the phase of the sampling clock can be aligned with the mid-point of the symbols in as few as 3 samplings, i.e., in no more than 4 symbols. This symbol mid-point is the point at which the eye opening is largest and the bit error rate is smallest. It is therefore possible to recover the clock timing giving minimum bit error rate (i.e., the optimum clock timing) in a short space of time.

The foregoing explanation concerned rapid recovery of clock timing from a clock timing recovery signal. An explanation will now be given of an embodiment which performs clock timing recovery by tracking frequency fluctuations that occur after clock timing has already been recovered in the manner of the first embodiment, or which performs clock timing recovery for continuous digital data.

FIG. 11 is a block diagram of a second embodiment of the present invention, and shows an example of the configuration of a demodulator which is equipped with a clock timing recovery circuit.

This demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5a. An IF signal is input to quadrature modulator 1. Oscillator 41 generates a carrier signal which is not synchronized with the IF signal and supplies this to quadrature detector 1. Analogue-to-digital converters 2 and 3 sample the outputs of quadrature detector 1 with the timing of the sampling clock supplied from clock timing recovery circuit 5a, and convert the outputs to digital signals. Baseband signal processing circuit 4 processes the sampled signals output by analogue-to-digital converters 2 and 3, outputs decoded signals, and also outputs the decision error (i.e., a decision error signal) obtained from these sampled signals to clock timing recovery circuit 5a.

Clock timing recovery circuit 5a comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31 and phase control circuit 32. System clock generator 6 generates a system clock with a predefined fixed period. Phase shift circuit 7 outputs, as the clock timing for sampling the baseband signal in the demodulator, corrected clock t_0 which corrects the phase of the system clock output by system clock generator 6. Sampling clock generator 31 generates a clock which alternately has a leading or trailing edge point which leads the leading or trailing edge point of corrected clock t_0 by a predefined timing difference δt , and a leading or trailing edge point which lags behind the leading edge or trailing edge point of corrected clock t_0 by the same timing difference δt . Sampling clock generator 31 outputs this clock as the sampling clock for the main signal lines. Phase control circuit 32 compares, on the basis of decision error signals from baseband signal processing circuit 4, the decision error obtained from the sampled signal at the leading or trailing edge point which leads by δt , with the decision error obtained from the sampled signal at the leading or trailing edge point which lags by δt , and on the basis of this comparison result, calculates the amount of phase shift of phase shift circuit 7. By controlling the amount of phase shift of phase shift circuit 7 on the basis of this calculation result, a leading edge or trailing edge of corrected clock t_0 can be brought into alignment with the optimum clock timing.

FIG. 12 shows the decision error in baseband signal processing circuit 4 as a function of sampling timing. Sampling at timings that deviate from the optimum timing (the timing at which the decision error is minimum) results in the absolute value or the square of the decision error tracing a convex curve with a downwards-pointing apex. FIG. 12 shows the results obtained by computer simulation of the root-mean-square (RMS) value of the decision error as a function of sampling timing under various fixed carrier-to-noise power ratios (C/N). In this simulation, the modulation and demodulation schemes were taken to be QPSK and differential detection, respectively, and the transmission system was assumed to be a Nyquist system with a roll-off factor of 0.6. It will be seen from FIG. 12 that the decision error, and thereby the bit error rate as well, becomes minimum at the timing at which the derivatives of the curves traced by the decision error become zero.

FIG. 13(a)-(i) show the signals at various parts of the circuit, as follows: FIG. 13(a) intermediate frequency signal input to quadrature detector 1, showing the configuration of a burst signal frame; FIG. 13(b) baseband signal (eye pattern) output from quadrature detector 1; FIG. 13(c) desired clock timing; FIG. 13(d) system clock output by system clock generator 6; FIG. 13(e) clock t_a which leads corrected clock t_0 output by phase shift circuit 7 by timing difference δt ; FIG. 13(f) corrected clock t_0 output by phase shift circuit 7; FIG. 13(g) clock t_b which lags corrected clock t_0 by timing difference δt ; FIG. 13(h) sampling clock output by sampling clock generator 31; FIG. 13(i) sampled signal output by analogue-to-digital converters 2 and 3.

As shown in FIG. 13(a)-(i), phase shift circuit 7 forms corrected clock t_0 , which is obtained by shifting the phase of system clock t . The amount of phase shift from t to t_0 is τ . Note, however, that $\tau=0$ when this clock timing recovery circuit 5a is in its initial state, and that when the clock timing is established, τ constitutes the time difference between system clock t and the clock timing at which the bit error rate becomes minimum. On the basis of corrected clock t_0 , sampling clock generator 31 forms two clocks t_a and t_b with a phase difference of $2\delta t$ and uses these two clocks to generate the sampling clock shown in FIG. 13(h). This sampling clock is supplied to analogue-to-digital converters 2 and 3 where it is used to sample the baseband signal. Phase control circuit 32 obtains, on the basis of the decision error signal e obtained from baseband signal processing circuit 4, the absolute values or the squares of the decision

errors e_a and e_b obtained using the timings of clocks t_a and t_b respectively. Phase control circuit 32 also obtains sampling timing correction $+\alpha$ or $-\alpha$ or 0 on the basis of e_a , e_b and difference δe . α ($\alpha > 0$) is the correction width, and can either be set to a constant value or can be changed adaptively according to difference δe . Phase control circuit 32 updates the sampling timing as follows:

- $\delta e > 0$: replace t_0 with $t_0 + \alpha$
- $\delta e < 0$: replace t_0 with $t_0 - \alpha$
- $\delta e = 0$: leave t_0 unchanged.

FIG. 14 serves to explain the operating principles and shows the relation between sampling timing and decision error. The sampling timing is repeatedly updated in phase shift circuit 7 on the basis of the above updating equations, and when δe has become zero, the derivative of the curve shown in FIG. 14 becomes zero and the mid-point t_0 between t and t coincides with the timing at which the decision error becomes minimum, or in other words with the clock timing at which the bit error rate becomes minimum.

Clock timing recovery circuit 5a in this second embodiment can cause the sampling timing to coincide with the clock timing at which the bit error rate becomes minimum, at a processing speed of the order of the symbol rate. Accordingly, because oversampling is not necessary, this clock timing recovery circuit can easily cope with high symbol rates and can also achieve reductions in power consumption. Furthermore, because the system clock is incorporated in the clock timing recovery circuit, the clock is not lost even if the IF signal level drops. In addition, because almost the entire constitution of the clock timing recovery circuit can be implemented with digital circuits, there is little clock jitter, and once the parameters δt and α have been set so that only a short time is required to establish the clock timing, it is unnecessary to make subsequent adjustments to these parameters. A non-adjusting circuit is therefore possible.

FIG. 15 is a block diagram of a third embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in the clock timing recovery circuit of a demodulator which uses a phase modulation scheme such as QPSK or $\pi/4$ shift QPSK for the modulation and a quasi-coherent detection scheme such as baseband differential detection for the demodulation.

The demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4a and clock timing recovery circuit 5b. The IF signal is input to quadrature detector 1. Oscillator 41 generates a carrier signal which is not synchronised with the IF signal and supplies this to quadrature modulator 1. Analogue-to-digital converters 2 and 3 respectively sample the in-phase and quadrature channel outputs from quadrature modulator 1 and convert these to digital signals. Baseband signal processing circuit 4a processes the sampled signals in the in-phase and quadrature channels output by analogue-to-digital converters 2 and 3, and thereby obtains a decoded signal for each channel. Clock timing recovery circuit 5b generates, from the phase component θ of the sampled signals, a sampling clock which it supplies to the analogue-to-digital converters.

Baseband signal processing circuit 4a comprises coordinate transform circuit 42, delay circuit 43 and decision circuit 44. Coordinate transform circuit 42 obtains the phase component by transforming the orthogonal coordinate representation of the sampled in-phase and quadrature signals to a polar coordinate representation. Delay circuit 43 causes the output of this coordinate transform circuit 42 to be delayed by one symbol period T . Decision circuit 44 obtains the decoded signal for each channel from the output of coordinate transform circuit 42 and the output of delay circuit 43: in other words, from the phase components of the two sampled signals which deviate by one symbol period.

Clock timing recovery circuit 5b comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31 and phase control circuit 32a. The phase component of the sampled signal obtained by coordinate transform circuit 42 in baseband signal processing circuit 4a is input to phase control circuit 32a, which controls the amount of phase shift of phase shift circuit 7 on the basis of this phase component. The operation of system clock generator 6 and phase shift circuit 7 is the same as in the first embodiment illustrated in FIG. 4 and as in the second embodiment illustrated in FIG. 11, and the operation of sampling clock generator 31 is the same as in the second embodiment.

The operating flow of the clock timing recovery in this third embodiment is shown in FIG. 16. This operating flow shows not only the operation of clock timing recovery circuit 5b but also the related operations of analogue-to-digital converters 2 and 3 and of coordinate transform circuit 42.

FIG. 17 shows an example of a specific configuration of sampling clock generator 31. This sampling clock generator 31 comprises phase lead circuit 51, phase delay circuit 52, and switch 53. Phase lead circuit 51 causes the timing of corrected clock t_0 to lead by δt . Phase delay circuit 52 causes the timing of corrected clock t to lag by δt . Switch 53 switches alternately between the outputs of these circuits in synchronisation with corrected clock t_0 .

FIG. 18 shows an example of a specific configuration of phase control circuit 32a. This circuit comprises delay circuit 61, adder 62, decision circuit 63, adder 64, absolute value circuit 65, switch 66, latches 67 and 68, adder 69, sign detector 70, up/down counter 71, multiplier 72, and accumulator 73. The phase component θ of the sampled signal is supplied from coordinate transform circuit 42 in baseband signal processing circuit 4a to this phase control circuit 32a. Delay circuit 61 causes this signal to be delayed by two symbol periods $2T$, and adder 62 obtains the difference between the phase component θ of the sampled signal and the output of delay circuit 61. Decision circuit 63 decides

the output of adder 62, and adder 64 calculates the difference between the output of adder 62 and the output of decision circuit 63, i.e., the decision error. Absolute value circuit 65 calculates the absolute value of the output of adder 64. Switch 66 distributes the output of absolute value circuit 65 to the two latches 67 and 68 in each symbol period. Latches 67 and 68 store the output of switch 66 for two symbol periods. Adder 69 obtains the difference δe between the outputs of the two latches 67 and 68 once every two symbols. Sign detector 70 obtains the sign of the output of adder 69. Up/down counter 71 counts the output of sign detector 70 and outputs a +1 or a -1 when its value has exceeded a fixed amount. Multiplier 72 multiplies the output of up/down counter 71 by the correction width α ($\alpha > 0$) and outputs the result as an amount of correction. Accumulator 73 accumulates these corrections and outputs them to phase shift circuit 7. In this example, the difference δe between the outputs of the two latches 67 and 68 can be expressed as follows:

$$\delta e = |\text{Err}[\theta_{2n+1} - \theta_{2n-1}]| - |\text{Err}[\theta_{2n} - \theta_{2n-2}]| \quad (4)$$

where θ_{2n} is the phase component of the $2n$ -th sampled signal and Err is a function expressing the decision error.

A squaring circuit can be used instead of absolute value circuit 65. An alternative configuration would be to use an accumulator instead of sign detector 70 and up/down counter 71, and to cause the amount of correction to change adaptively in accordance with the amount of error.

FIG. 19 shows another example of the configuration of sampling clock generator 31. This sampling clock generator 31 comprises frequency divider 81, inverter 82, phase lead circuit 83, phase delay circuit 84, inverters 85 and 86, delay circuits 87 and 88, AND circuits 89 and 90, and OR circuit 91. Frequency divider 81 halves the frequency of corrected clock t_0 . Inverter 82 inverts the clock that is output by frequency divider 81. Phase lead circuit 83 causes the timing of the clock output by inverter 82 to lead by δt , while phase delay circuit 84 causes the timing of the clock output by frequency divider 81 to lag by δt . Inverters 85 and 86 respectively invert the clocks output by phase lead circuit 83 and phase delay circuit 84. Delay circuits 87 and 88 respectively delay the outputs of inverters 85 and 86 by a very small time t_g . AND circuit 89 obtains the logical product of the clock that is output by phase lead circuit 83 and the clock obtained by inverting this clock and then delaying it by t_g (i.e., the output of delay circuit 87). AND circuit 90 obtains the logical product of the clock that is output by phase delay circuit 84 and the clock obtained by inverting this clock and then delaying it by t_g (i.e., the output of delay circuit 88). OR circuit 91 obtains the logical sum of the clocks output by AND circuit 89 and 90.

FIG. 20 shows the sampling clock that is output by the sampling clock generator shown in FIG. 19. With the configuration shown in FIG. 19, the duty ratio of the sampling clock output by the sampling clock generator does not reach 50%. However, analogue-to-digital converters capable of supporting such a clock are already commercially available, and provided that t_g is made longer than the hold time required by the analogue-to-digital converter, these will certainly be useable.

FIG. 21 is a block diagram of a fourth embodiment of the present invention and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in a clock timing recovery circuit of a demodulator which uses 2^n QAM ($n = 1, 2, \dots$) modulation as the modulation scheme and coherent detection for the demodulation scheme. The demodulator comprises quadrature detector 1, carrier recovery circuit 101, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4b and clock timing recovery circuit 5c. The IF signal is input to quadrature detector 1, which performs quadrature detection using the carrier signal supplied from carrier recovery circuit 101. Carrier recovery circuit 101 generates the carrier synchronously with the IF signal. Analogue-to-digital converters 2 and 3 respectively convert the outputs in the in-phase and quadrature channels of quadrature detector 1 to digital signals. Baseband signal processing circuit 4b performs data decision on the sampled signals in the in-phase and quadrature channels output by analogue-to-digital converters 2 and 3, and thereby obtains a decoded signal for each channel. Clock timing recovery circuit 5c generates, from a decision error signal obtained from baseband signal processing circuit 4b, the sampling clock to be supplied to analogue-to-digital converters 2 and 3.

Baseband signal processing circuit 4b comprises two decision circuits 102 and 103, and adder 104. Decision circuits 102 and 103 perform data decision on the sampled signals in the in-phase and quadrature channels, thereby obtaining a decoded signal for each channel. Adder 104 calculates the difference between the sampled signal in the in-phase channel and the decoded signal, and outputs this as a decision error signal.

Clock timing recovery circuit 5c comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31, and phase control circuit 32b. The configuration and operation of system clock generator 6, phase shift circuit 7 and sampling clock generator 31 are the same as in the embodiment described above. The circuit remaining after delay circuit 61, adder 62, decision circuit 63 and adder 64 have been removed from the circuit illustrated in FIG. 18 can be utilised as phase control circuit 32b.

FIG. 22 is a block diagram of a fifth embodiment of the present invention, and shows the configuration of a clock

timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in the clock timing recovery circuit of a demodulator which employs 2^{2n} QAM ($n = 1, 2, \dots$) modulation as the modulation scheme and coherent detection for the demodulation scheme.

The demodulator comprises quadrature detector 1, carrier recovery circuit 101, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4c and clock timing recovery circuit 5d. The IF signal is input to quadrature detector 1 which performs quadrature detection using the carrier signal supplied from carrier recovery circuit 101. Carrier recovery circuit 101 generates a carrier signal synchronised with the IF signal. Analogue-to-digital converters 2 and 3 respectively convert the outputs in the in-phase and quadrature channels of quadrature detector 1 to digital signals. Baseband signal processing circuit 4c performs data decision on the sampled signals in the in-phase and quadrature channels that are output by analogue-to-digital converters 2 and 3, thereby obtaining a decoded signal for each channel. Clock timing recovery circuit 5d generates, from the decision error signals obtained from baseband signal processing circuit 4c for each channel, sampling clocks t_a and t_b for supply to analogue-to-digital converters 2 and 3.

Baseband signal processing circuit 4c comprises two decision circuits 102 and 103, and likewise two adders 104 and 105. Decision circuits 102 and 103 perform data decision on the sampled signals in the in-phase and quadrature channels, thereby obtaining a decoded signal for each channel. Adder 104 calculates the difference between the sampled signal and the decoded signal in the in-phase channel and outputs this as a decision error signal, while adder 105 calculates the difference between the sampled signal and the decoded signal in the quadrature channel and outputs this as a decision error signal.

Clock timing recovery circuit 5d comprises system clock generator 6, phase shift circuit 7, phase lead circuit 51, phase delay circuit 52, and phase control circuit 32c.

In this fifth embodiment, rather than alternately selecting one of the two clocks t_a and t_b , the signals in the in-phase and quadrature channels are respectively sampled using these two clocks t_a and t_b . For this reason, switch 53 of the sampling clock generator shown in FIG.17 is unnecessary, and the two clocks t_a and t_b are obtained, from corrected clock to output by phase shift circuit 7, by phase lead circuit 51 and phase delay circuit 52.

FIG.23 shows an example of the configuration of phase control circuit 32c. This phase control circuit 32c comprises absolute value circuits 65a and 65b, adder 69, sign detector 70, up/down counter 71, multiplier 72, and accumulator 73. Absolute value circuit 65a calculates the absolute value of the decision error signal in the in-phase channel, while absolute value circuit 65b calculates the absolute value of the decision error signal in the quadrature channel. Adder 69 calculates the difference between the outputs of the two absolute value circuits 65a and 65b. Sign detector 70 obtains the sign of the output of adder 69. Up/down counter 71 counts the output of sign detector 70 and outputs a +1 or a -1 when and only when this value exceeds a fixed quantity. Multiplier 72 multiplies the output of up/down counter 71 by the correction width α ($\alpha > 0$) and outputs the result as an amount of correction. Accumulator 73 accumulates these corrections and outputs them to phase shift circuit 7.

In this example configuration as well, as in the example configuration shown in FIG.18, a squaring circuit can be used instead of absolute value circuits 65a and 65b. An alternative configuration that is possible is to use an accumulator instead of sign detector 70 and up/down counter 71, and to cause the amount of correction to change adaptively according to the amount of error.

FIG.24 is a block diagram of a sixth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment differs from the third embodiment in that it provides analogue-to-digital converters 111 and 112 and coordinate transform circuit 113 in clock timing recovery circuit 5e, separately from the main signal lines; and in that it supplies corrected clock to analogue-to-digital converters 2 and 3 in the main signal lines.

As in the third embodiment, clock timing recovery circuit 5e comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31 and phase control circuit 32a, but additionally comprises analogue-to-digital converters 111 and 112 and coordinate transform circuit 113. The clock from sampling clock generator 31 is supplied to analogue-to-digital converters 111 and 112, and these respectively sample the signals in the in-phase and quadrature channels from quadrature detector 1. Coordinate transform circuit 113 transforms the sampled signals in the in-phase and quadrature channels from orthogonal to polar coordinates, thereby obtaining the phase component θ . Phase control circuit 32a controls the amount of phase shift of phase shift circuit 7 on the basis of this phase component θ .

Although this embodiment has a larger circuit scale than the second to the fifth embodiments, an improved bit error rate can be obtained because the influence of δt can be excluded from the decoded signals.

This embodiment has been explained on the assumption that QPSK modulation or $\pi/4$ shift QPSK modulation or some other phase modulation scheme has been used for the modulation, and that a quasi-coherent detection scheme such as baseband differential detection is used for the demodulation. However, by using a carrier recovery circuit instead of oscillator 41, and by providing, in place of coordinate transform circuit 113, a circuit which performs data decision on the sampled signals to obtain the decision errors at those signal points, this embodiment can be implemented in similar manner when 2^{2n} QAM ($n = 1, 2, \dots$) modulation is used as the modulation scheme and coherent

detection is used for the demodulation.

FIG. 25 shows an example of the configuration of a phase control circuit used instead of coordinate transform circuit 113 and phase control circuit 32a when the embodiment shown in FIG. 24 is revised and 2^n QAM ($n = 1, 2, \dots$) modulation is used as the modulation scheme, and coherent detection is used as the demodulation scheme.

5 This phase control circuit comprises decision circuits 63a and 63b, adders 64a and 64b, absolute value circuits 65a and 65b, adder 69, sign detector 70, up/down counter 71, multiplier 72 and accumulator 73. Decision circuits 63a and 63b perform data decision on the sampled signals in the in-phase and quadrature channels respectively. Adders 64a and 64b calculate, respectively, the difference between the sampled signal in the channel and the decision output of decision circuits 63a and 63b in respect of this sampled signal. In other words, adders 64a and 64b calculate the decision error. Absolute value circuits 65a and 65b respectively calculate the absolute values of the outputs of adders 64a and 64b. Adder 69 calculates the difference δe between the outputs of absolute value circuits 65a and 65b. Sign detector 70 obtains the sign of the output of adder 69. Up/down counter 71 counts the outputs of sign detector 70 and outputs a +1 or a -1 when, and only when, this value exceeds a fixed quantity. Multiplier 72 multiplies the output of up/down counter 71 by the correction width α ($\alpha > 0$), and outputs this as the amount of correction. Accumulator 73 accumulates these corrections and outputs them to phase shift circuit 7.

FIG. 26 is a block diagram of a seventh embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in a clock timing recovery circuit of a demodulator which uses 2^n QAM ($n = 1, 2, \dots$) modulation as the modulation scheme and coherent detection as the demodulation scheme. This seventh embodiment is similar to the sixth embodiment in that it provides analogue-to-digital converters 111 and 112 separately from the main signal lines, and in that it supplies corrected clock t_0 to analogue-to-digital converters 2 and 3 of the main signal lines. However, it differs significantly from the sixth embodiment in that it uses different clocks t_a and t_b for sampling the in-phase and quadrature channels in clock timing recovery circuit 5f.

25 Clock timing recovery circuit 5f comprises system clock generator 6, phase shift circuit 7, phase lead circuit 51, phase delay circuit 52, analogue-to-digital converters 111 and 112, and phase control circuit 32d. System clock generator 6 generates the reference clock. Phase shift circuit 7 generates corrected clock t_0 by correcting the system clock on the basis of the output of phase control circuit 32d, and outputs this corrected clock t_0 to analogue-to-digital converters 2 and 3 as the sampling clock, and also outputs it to phase lead circuit 51 and phase delay circuit 52. Phase lead circuit 51 causes the phase of corrected clock t_0 to advance by δt , while phase delay circuit 52 causes it to lag by δt . Analogue-to-digital converter 111 samples the signal in the in-phase channel using clock t_a output by phase lead circuit 51, while analogue-to-digital converter 112 samples the signal in the quadrature channel using clock t_b output by phase delay circuit 52. Phase control circuit 32d obtains the amount of phase correction from the outputs of analogue-to-digital converters 111 and 112, and thereby controls the amount of phase shift of phase shift circuit 7. The phase control circuit shown in FIG. 25 can be used as phase control circuit 32d.

35 As regards the foregoing embodiments, in the first embodiment, when a burst signal is received, the clock timing can be recovered rapidly using only a clock timing recovery signal added to the signal frame. As opposed to this, in the second to the seventh embodiments, highly accurate clock timing recovery can be carried out for continuous signals and for the portion of a burst signal other than the clock timing recovery signal portion, by tracking frequency fluctuations. Accordingly, when a burst signal is received, it is preferable to recover the clock timing using a clock timing recovery signal in accordance with the first embodiment, and otherwise it is preferable to recover the clock timing in accordance with any of the second to the seventh embodiments. An embodiment of this sort will now be explained.

FIG. 27 is a block diagram of an eighth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This eighth embodiment combines the first and second embodiments, and its demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5g, while clock timing recovery circuit 5g comprises system clock generator 6, phase shift circuit 7, control circuit 8a, sampling clock generator 31, and switch 11b. Control circuit 8a comprises counter 9, phase estimation circuit 10, switch 11a and phase control circuit 32.

50 The operation of all parts other than switches 11a and 11b is as explained in connection with the first embodiment or the second embodiment. Switch 11a selects the output of counter 9 with the timing of the clock timing recovery signal. when the clock timing recovery signal ends, switch 11a first of all selects the output of phase estimation circuit 10 and then selects the output of phase control circuit 32. In each case it supplies the output to phase shift circuit 7. Switch 11b selects, as the sampling clock for sampling the clock timing recovery signal, the clock which counter 9 causes phase shift circuit 7 to output, and subsequently selects the output of sampling clock generator 31 as the sampling clock for sampling the baseband signal that follows the clock timing recovery signal.

55 In other words, switch 11a selects the output of counter 9 and switch 11b selects the output of phase shift circuit 7 with the timing of the clock timing recovery signal. As a result, the clock that is output from clock timing recovery circuit 5g as the sampling clock has the phase of its n -th leading edge point or trailing edge point from the origin ($n =$

1, 2, 3, ...), where one leading edge point or trailing edge point of the system clock is taken as the origin, shifted by $n \times \Delta t$ relative to the phase of the system clock (where Δt is a predefined amount of phase shift). Phase estimation circuit 10 then uses the sampled signal obtained on the basis of this sampling clock to estimate the phase difference between the phase of the system clock and the clock timing at which the bit error rate becomes minimum.

Switch 11a selects the output of phase estimation circuit 10 when this circuit has estimated the aforesaid phase difference on the basis of a prescribed number of sampled signals. As a result, the amount of phase shift of phase shift circuit 7 is established on the basis of an estimated phase difference.

when the clock timing recovery signal is finished, switch 11a selects the output of phase control circuit 32 and switch 11b selects the output of sampling clock generator 31. As a result, there is output from clock timing recovery circuit 5g, as a sampling clock, a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock that is output by phase shift circuit 7 by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt . Phase control circuit 32 then corrects the amount of phase shift of phase shift circuit 7 on the basis of sampled signals obtained using these sampling clocks.

The present embodiment is thus capable of rapid acquisition of optimum clock timing using a clock timing recovery signal, and also of tracking any frequency fluctuations of the signal that follows the clock timing recovery signal. Accordingly, although the circuit scale is relatively large, this embodiment is very effective when rapid acquisition of a highly accurate clock is required.

It is also possible to utilise modified versions of the second to the seventh embodiments to acquire optimum clock timing using a clock timing recovery signal. Such an embodiment will be explained below.

FIG.28 is a block diagram of a ninth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided.

This demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5h. Clock timing recovery circuit 5h comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31, phase control circuit 32e, and squaring circuit 121.

In this embodiment, it is the sampled signal itself, rather than the decision error of the sampled signal, which is input to clock timing recovery circuit 5h. Squaring circuit 121 squares the sampled signal obtained by sampling on the basis of the sampling clock. Phase control circuit 32e compares the amplitude of the squared sampled signal obtained by sampling at leading edge or trailing edge points which lead the clock output by phase shift circuit 7 by δt , with the amplitude at leading edge or trailing edge points which lag by δt , and calculates the amount of phase shift of phase shift circuit 7 on the basis of the result of this comparison.

FIG.29 to FIG.31 serve to explain the operation of clock timing recovery circuit 5h. FIG.29 shows the operation flow, FIG.30(a)-(j) show the timing of the various signals, and FIG.31 shows the relation between the sampling timing and the square of the sampled signal.

As shown in FIG.30(a), the IF signal which is input to the demodulator illustrated in FIG.28 has a burst frame configuration comprising a clock timing recovery signal (BTR), a frame synchronisation signal (UW), and data. FIG.30 (b)-(j) show, in enlarged form, a portion of the clock timing recovery signal and of associated signals and clocks present at various locations in the demodulator. The sinusoidal baseband signal shown in FIG.30(b) is obtained when the clock timing recovery signal is detected and has its bandwidth limited. The desired clock timing which gives the smallest bit error rate for this baseband signal is the signal shown in FIG.30(c). Clock timing recovery circuit 5h utilises the fact that the baseband signal constitutes the sine wave shown in FIG.30(b), and recovers from this signal the desired clock timing shown in FIG.30(c).

To accomplish this, phase shift circuit 7 corrects system clock t shown in FIG.30(d) by τ , thereby generating corrected clock t_0 shown in FIG.30(f). Note, however, that $\tau=0$ when clock timing recovery circuit 5h is in its initial state, and that when clock timing has been established, τ constitutes the time difference between system clock t shown in FIG.30(d) and the clock timing. On the basis of corrected clock t_0 , sampling clock generator 31 generates two clocks t_a and t_b with a phase difference of $2\delta t$, and further forms the sampling clock shown in FIG.30(h), for example, by switching between these two clocks at every symbol. This sampling clock is then used to sample the baseband signal at analogue-to-digital converters 2 and 3. As a result, a sampled signal is obtained, and this is the digital signal shown in FIG.30(i). This sampled signal is squared by squaring circuit 121, giving the signal shown in FIG.30(j).

It will be seen that the timing giving the maximum squares in FIG.30(j) has to be extracted to obtain the clock timing shown of FIG.30(b). In other words, as shown in FIG.31, the clock timing is the timing at which the square of the sampled signal is not zero and the derivative is zero. Utilising this, the amount of correction of the sampling timing is determined by phase control circuit 32e from the output of squaring circuit 121.

In other words, the squares R_a and R_b of the sampled signal at the respective timings are obtained, and the amount of correction of the sampling timing ($+\alpha$ or $-\alpha$ or 0) is found on the basis of the difference δR between R_a and R_b . α ($\alpha > 0$) is the correction width, and can either be set to a constant value or can be changed adaptively according to difference δR . Phase shift circuit 7 updates the sampling timing as follows:

$\delta R < 0$: replace t_0 with $t_0 + \alpha$

$\delta R > 0$: replace t_0 with $t_0 - \alpha$

$\delta R = 0$: leave t_0 unchanged.

When δR has become zero as a result of repetitions of this updating, the derivative of the curve shown in FIG.31 becomes zero and mid-point to between t_a and t_b coincides with the clock timing at which the bit error rate becomes minimum.

FIG.32 serves to explain the operation of the clock timing recovery circuit in its pseudostable state. when the timing of corrected clock t_0 has coincided with $\pm T/2$, there arises a pseudostable state in which although the derivative becomes zero, clock timing cannot be obtained. However, this pseudostable state arises only when clock timing recovery circuit 5h is in its initial state ($\tau=0$) or when the difference between system clock timing t and the clock timing of the received signal is exactly $\pm T/2$. The probability of this state occurring is therefore very small. A countermeasure against the pseudostable state would be to correct the corrected clock t_0 by $\pm T/2$ if the squares R_a and R_b of the sampled signal were less than a given threshold.

FIG.33 is a block diagram of a tenth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in the clock timing recovery circuit of a demodulator which uses a phase modulation scheme such as QPSK or $\pi/4$ shift QPSK for the modulation and a quasi-coherent detection scheme such as baseband differential detection for the demodulation.

The demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5i. Clock timing recovery circuit 5i comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31, squares adding circuit 122, and phase control circuit 32e. Squares adding circuit 122 comprises two multipliers which square the respective signals in the in-phase and quadrature channels, and an adder which adds the outputs of these two multipliers.

FIG.34 shows an example of a specific configuration of phase control circuit 32e. This circuit comprises switch 66, latches 67 and 68, adder 69, sign detector 70, up/down counter 71, multiplier 72 and accumulator 73. Switch 66 distributes the square (R) of the input sampled signal to the two latches 67 and 68 at every symbol. Latches 67 and 68 store the output of switch 66 for a time interval length corresponding to two symbols. Once every two symbols, adder 69 obtains the difference δR between the outputs of the two latches 67 and 68. Sign detector 70 obtains the sign of the output of adder 69. Up/down counter 71 counts the output of sign detector 70 and outputs a +1 or a -1 when, and only when, this value exceeds a fixed quantity. Multiplier 72 multiplies the output of up/down counter 71 by the correction width α ($\alpha > 0$) and outputs the result as the amount of correction. Accumulator 73 accumulates these corrections and outputs them to phase shift circuit 7.

An accumulator can be used instead of sign detector 70 and up/down counter 71, and the amount of correction can be changed adaptively in accordance with the difference δR .

FIG.35 is a block diagram of an eleventh embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment implements the present invention in a clock timing recovery circuit of a demodulator which uses 2^{2n} QAM ($n = 1, 2, \dots$) modulation as the modulation scheme and coherent detection as the demodulation scheme. Note that in this case it is assumed that a binary clock timing recovery signal is inserted at the transmitting side in order for a sine wave to be obtained after the quadrature detection.

The demodulator in this embodiment comprises quadrature detector 1, carrier recovery circuit 101, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5j. Clock timing recovery circuit 5j comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31a, squaring circuits 123 and 124, and phase control circuit 32f. Sampling clock generator 31a comprises phase lead circuit 51 and phase delay circuit 52.

FIG.36 shows an example of a specific configuration of phase control circuit 32f used in this embodiment. This circuit comprises adder 69, sign detector 70, up/down counter 71, multiplier 72 and accumulator 73. Adder 69 calculates the difference δR of the squares of the sampled values in the in-phase and quadrature channels. Sign detector 70 obtains the sign of the output of adder 69. Up/down counter 71 counts the output of sign detector 70 and outputs a +1 or a -1 when, and only when, this value exceeds a fixed quantity. Multiplier 72 multiplies the output of up/down counter 71 by a correction width α ($\alpha > 0$) and outputs the result as the amount of correction. Accumulator 73 accumulates these corrections and outputs them to phase shift circuit 7.

FIG.37 is a block diagram of a twelfth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which this is provided. This embodiment differs from the tenth embodiment in that it uses corrected clock t_0 for the sampling in the main signal lines, and in that it performs, in the clock timing recovery circuit, a sampling which is separate from the main signal lines.

The demodulator comprises quadrature detector 1, oscillator 41, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5k. Clock timing recovery circuit 5k comprises, in similar

manner to the tenth embodiment, system clock generator 6, phase shift circuit 7, sampling clock generator 31, squares adding circuit 122, and phase control circuit 32e. It additionally comprises analogue-to-digital converters 111 and 112. Corrected clock t_0 output by phase shift circuit 7 is supplied to sampling clock generator 31 and is also output as the sampling clock for the main signal lines. Sampling clock generator 31 alternately supplies analogue-to-digital converters 111 and 112 with a clock which leads the timing of corrected clock t_0 by δt and a clock which lags behind the timing of corrected clock t_0 by δt . Analogue-to-digital converters 111 and 112 use these clocks to sample, in a system separate from the main signal lines, the baseband signal in the in-phase and quadrature channels output from quadrature detector 1. Apart from this, the operation of this twelfth embodiment is the same as that of the tenth embodiment.

Although this twelfth embodiment has a larger circuit scale than the tenth and eleventh embodiments, an improved bit error rate can be obtained because the influence of δt can be excluded from the decoded signals.

The explanation given here has assumed that QPSK or $\pi/4$ shift QPSK or another phase modulation scheme was used for the modulation, and that a quasi-coherent detection scheme such as baseband differential detection was used for the demodulation. However, this embodiment can also support a 2^{2n} QAM ($n = 1, 2, \dots$) modulation scheme if a binary clock timing recovery signal is inserted at the transmitting side so that a sine wave is obtained after the quadrature detection.

FIG.38 is a block diagram of a thirteenth embodiment of the present invention, and shows the configuration of a clock timing recovery circuit and of a demodulator in which it is provided. This embodiment implements the present invention in a clock timing recovery circuit of a demodulator which uses a 2^{2n} QAM ($n = 1, 2, \dots$) modulation scheme for the modulation and coherent detection for the demodulation. In this embodiment, however, it is assumed that a binary clock timing recovery signal has been inserted at the transmitting side so that a sine wave is obtained after the quadrature detection.

The constitution of this embodiment is similar to that of the eleventh embodiment, but it differs from the eleventh embodiment in that, like the twelfth embodiment, it has analogue-to-digital converters additional to those of the main signal lines, and in that it supplies corrected clock t_0 to the analogue-to-digital converters of the main signal lines.

The demodulator in this thirteenth embodiment comprises quadrature detector 1, carrier recovery circuit 101, analogue-to-digital converters 2 and 3, baseband signal processing circuit 4, and clock timing recovery circuit 5m. Clock timing recovery circuit 5m comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31a, squaring circuits 123 and 124, and phase control circuit 32f. It additionally comprises analogue-to-digital converters 111 and 112. Corrected clock t_0 output by phase shift circuit 7 is supplied to sampling clock generator 31a and is also output as the sampling clock for the main signal lines. Sampling clock generator 31a supplies, to analogue-to-digital converters 111 and 112 respectively, clock t_a which leads the timing of corrected clock t_0 by δt , and clock t_b which lags behind the timing of corrected clock t_0 by δt . Analogue-to-digital converters 111 and 112 use these clocks to sample the baseband signals in the in-phase and quadrature channels output from quadrature detector 1, this being done in a separate system from the main signal lines.

FIG.39 is a block diagram of another example of the configuration of clock timing recovery circuit 5i used in the tenth embodiment, and shows an example of a configuration designed to deal with the pseudostable state shown in FIG.32. This clock timing recovery circuit shifts the timing of corrected clock t_0 by a half period when it has been detected from the baseband signal that the timing of the system clock and the clock timing of the received signal are out by a half period.

This clock timing recovery circuit comprises system clock generator 6, phase shift circuit 7, sampling clock generator 31, squares adding circuit 122 and phase control circuit 32e, and additionally comprises kick-off circuit 131 and adder 132. Kick-off circuit 131 detects a pseudostable state from the sampled signals in the in-phase and quadrature channels, and in this case only, outputs a value of $T/2$ (where T is the symbol period). Adder 132 adds the output of kick-off circuit 131 and the output of phase control circuit 32e, and outputs the result to phase shift circuit 7.

FIG.40 is a block diagram showing an example of a specific configuration for a kick-off circuit. This kick-off circuit comprises multipliers 141 and 142, adder 143, comparator 144, counter 145 and ROM 146. Multipliers 141 and 142 respectively square the sampled signals in the in-phase and quadrature channels. Adder 143 adds the outputs of multipliers 141 and 142. Comparator 144 compares the output value of adder 143 with a threshold, and if the output of adder 143 is smaller, outputs a "1", and otherwise outputs a "0". Counter 145 counts the outputs of comparator 144 and outputs a "1" when this reaches or exceeds a given value. ROM 146 outputs $T/2$ when the output of counter 145 is "1", and otherwise outputs "0".

FIG.41 is a block diagram showing another example of the configuration of a kick-off circuit, and FIG.42(a)-(h) show the signal waveforms in the pseudostable state corresponding to that of FIG.30(b)-(j).

The kick-off circuit shown in FIG.41 utilises the fact that the sign of the baseband signal when a pseudostable state has arisen becomes constant, as shown in FIG.42(a). Switch 151, latches 153 and 155, multiplier 157, sign detector 159 and counter 161 are provided for the in-phase channel, and switch 152, latches 154 and 156, multiplier 158, sign detector 160 and counter 162 are provided for the quadrature channel. OR circuit 163 and ROM 164 are also provided. Switch 151 switches the sampled signal in the in-phase channel to the two latches 153 and 155 at each

symbol, while switch 152 likewise switches the sampled signal in the quadrature channel to the two latches 154 and 156. Multiplier 157 multiplies the outputs of latches 153 and 155, while multiplier 158 multiplies the outputs of latches 154 and 156. Sign detectors 159 and 160 obtain the signs of the outputs of multipliers 157 and 158 respectively. Counters 161 and 162 respectively count the outputs of sign detectors 159 and 160, and output a "1" when these reach or exceed a given value. OR circuit 163 obtains the logical sum of counters 161 and 162. ROM 164 outputs T/2 when the output of OR circuit 163 is "1" and otherwise outputs 0.

The explanations given with reference to FIG.39 to FIG.42 related to examples of configurations for avoiding a pseudostable state in the clock timing recovery circuit of the tenth embodiment. If required, a pseudostable state can be avoided in similar manner in the other embodiments as well by making some modifications to these configurations. Namely, when it has been detected from the baseband signal that the timing of the system clock and the clock timing of the received signal diverge by a half period, the pseudostable state of the clock timing recovery circuit can be avoided by shifting the clock timing by a half period. Clock timing can also be established rapidly when the clock timing recovery circuit is in the vicinity of the pseudostable state, by moving it from this state.

As has been explained above, unlike a tank-limiter clock recovery circuit using IF signal operation, with a clock timing recovery circuit according to this invention the clock is not lost when the level of the IF signal decreases. Furthermore, because there is no need for oversampling such as employed in a clock recovery circuit using a binary quantised digital phase-locked loop, and because a processing speed of the order of the symbol rate is sufficient, a clock timing recovery circuit according to this invention can readily cope with high data transmission rates. Moreover, because processing speed can be restricted to the order of the symbol rate, low power consumption is a possibility. Furthermore, because almost all the constitutional elements of a clock timing recovery circuit according to the present invention can be constructed from digital circuits, it is not necessary to adjust parameters once they have been set, thereby making possible a non-adjusting circuit.

Claims

1. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
 phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal; and
 control means for controlling the amount of phase shift of this phase shift means;
 wherein a signal for clock timing recovery is added to the baseband signal; and
 the control means includes:
 first means which causes there to be output from the phase shift means, as a sampling clock for sampling the signal for clock timing recovery, a first clock whereof the phase of its n-th leading edge point or trailing edge point ($n = 1, 2, 3, \dots$) from the origin, where one leading edge point or trailing edge point of the system clock is taken as the origin, is phase-shifted by $n \times \Delta t$ relative to the phase of the system clock (where Δt is a pre-defined amount of phase shift); and
 second means which estimates, from the sampled signal obtained by sampling the signal for clock timing recovery, the phase difference between the phase of the system clock and the clock timing at which the bit error rate becomes minimum, and which, on the basis of this estimated phase difference, causes there to be output from the phase shift means the clock timing for sampling the baseband signal that follows the signal for clock timing recovery.

2. A clock timing recovery circuit according to Claim 1, comprising:

sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock that is output by the phase shift means by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; and
 means which selects the clock which the control means, using the first means, makes the phase shift means output, as the sampling clock for sampling the signal for clock timing recovery, and which selects the output of the sampling clock generating means as the sampling clock for sampling the baseband signal that follows the signal for clock timing recovery;
 wherein the aforesaid second means includes arithmetic means which calculates the amount of phase shift of the phase shift means by comparing decision errors obtained from the sampled signal at leading or trailing edge points that lead by δt , with decision errors obtained from the sampled signal at leading or trailing edge

points that lag by δt .

3. A clock timing recovery circuit comprising:

5 clock generating means for generating a system clock which repeats with a fixed period;
 phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
 timing for sampling the baseband signal obtained by detection of the received signal; and
 control means for controlling the amount of phase shift of this phase shift means;
 10 wherein there is provided sampling clock generating means which generates a second clock with leading or
 trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing
 difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge
 points of the first clock by the same timing difference δt ; and
 the control means includes arithmetic means which calculates the amount of phase shift of the phase shift
 15 means by comparing information relating to the phase error of the clock timing, said information being obtained
 respectively from the sampled signals obtained by sampling the baseband signal using the second and third
 clocks as the respective sampling clocks.

4. A clock timing recovery circuit according to Claim 3, wherein the information relating to phase error is the decision
 20 error of the phase component of the sampled signals obtained by the sampling.

5. A clock timing recovery circuit according to Claim 3, wherein the baseband signal is a signal obtained by coherent
 detection, and the information relating to phase error is the decision errors of the signal points of the sampled
 signals obtained by the sampling.

25 6. A clock timing recovery circuit according to Claim 3, wherein the baseband signal contains a clock timing recovery
 signal, and the information relating to phase error is the amplitudes of the sampled signals obtained by sampling
 this clock timing recovery signal.

7. A clock timing recovery circuit according to Claim 6 and having means which shifts the timing of the first clock by
 30 a half period when it has been detected from the clock timing recovery signal that the timing of the system clock
 and the clock timing of the baseband signal deviate by a half period.

8. A clock timing recovery circuit according to any of Claims 3 to 7, wherein:

35 the sampling clock generating means includes means which alternately selects the second clock and the third
 clock and outputs these as one clock; and
 the control means compares the information relating to phase error obtained alternately in respect of the sec-
 ond clock and the third clock.

40 9. A clock timing recovery circuit according to any of Claims 3 to 7 wherein:

the sampling clock generating means outputs the second clock and the third clock separately; and
 the control means compares the phase error related information obtained separately in respect of the second
 clock and the third clock.

45 10. A clock timing recovery circuit according to Claim 9 wherein:

the baseband signal includes an in-phase channel signal and a quadrature channel signal;
 the second clock is output as a sampling clock for one of the in-phase channel and the quadrature channel,
 50 and the third clock is output as a sampling clock for the other channel; and
 the arithmetic means includes means which compares the phase error related information obtained respec-
 tively from the in-phase channel and the quadrature channel.

11. A clock timing recovery circuit according to any of Claims 3 to 10, wherein the second and third clocks generated
 55 by the sampling clock generating means are output to the main signal lines as sampling clocks for decoding the
 digital data from the baseband signal.

12. A clock timing recovery circuit according to any of Claims 3 to 10 wherein:

the first clock is output to the main signal lines as a sampling clock for decoding the transmitted signal from the baseband signal; and there is provided:

sampling means which uses the second clock and the third clock to sample the baseband signal in separate lines from the main signal lines; and

means for obtaining phase error related information from the output of this sampling means.

13. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;

phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal; and

control means for controlling the amount of phase shift of this phase shift means;

wherein a signal for clock timing recovery is added to the baseband signal; and

there is provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; and

the control means includes:

first arithmetic means which calculates the amount of phase shift of the phase shift means by comparing the amplitudes of the sampled signals respectively obtained by sampling the signal for clock timing recovery using the second and third clocks respectively as sampling clocks; and

second arithmetic means which calculates the amount of phase shift of the phase shift means by comparing the decision errors obtained from the sampled signals when the baseband signal following the signal for clock timing recovery is sampled using the second and third clocks respectively as sampling clocks.

14. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;

phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal; and

control means for controlling the amount of phase shift of the phase shift means on the basis of the decision errors obtained from the sampled signals obtained by sampling the baseband signal;

wherein there is provided sampling clock generating means which generates and outputs as the sampling clock for the main signal lines a second clock which alternately has a leading edge or trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point of the first clock by the same timing difference δt ; and

the control means includes arithmetic means which compares the decision errors obtained from sampled signals at the leading edge or trailing edge point that leads by δt , with the decision errors obtained from sampled signals at the leading edge or trailing edge point that lags by δt , and on this basis calculates the amount of phase shift of the phase shift means.

15. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;

phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling, in the main signal lines, the baseband signal obtained by detection of the received signal; and

control means for controlling the amount of phase shift of the phase shift means on the basis of the decision errors obtained from the sampled signals obtained by sampling the baseband signal;

wherein there is provided:

sampling clock generating means for generating a second clock which alternately has a leading edge or trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point of the first clock by the same timing difference δt ; and

sampling means which uses this second clock to sample the baseband signal in separate lines from the main signal lines;

and wherein the control means includes arithmetic means which compares the decision errors obtained from

sampled signals at the leading edge or trailing edge point that leads by δt , with the decision errors obtained from sampled signals at the leading edge or trailing edge point that lags by δt , and on this basis calculates the amount of phase shift of the phase shift means.

5 16. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
10 timing for sampling the baseband signal obtained by detection of the received signal; and
control means for controlling the amount of phase shift of the phase shift means on the basis of the decision errors of the phase components of the sampled signals obtained by sampling the baseband signal, or on the basis of the decision errors of the signal points of the sampled signals obtained by sampling the baseband signal;

15 wherein there is provided sampling clock generating means which generates and outputs as the sampling clock for the main signal lines a second clock which alternately has a leading edge or trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point of the first clock by the same timing difference δt ; and

20 the control means includes arithmetic means which compares the decision errors of the phase components obtained from sampled signals at the leading edge or trailing edge point that leads by δt , with the decision errors of the phase components obtained from sampled signals at the leading edge or trailing edge point that lags by δt , and on this basis calculates the amount of phase shift of the phase shift means.

25 17. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
30 timing for sampling a baseband signal obtained by coherent detection; and
control means for controlling the amount of phase shift of the phase shift means on the basis of the decision errors of the signal points of the sampled signals obtained by sampling the baseband signal;

35 wherein there is provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , and which outputs the second clock as the sampling clock for one of the in-phase channel and quadrature channel in the main signal lines, and outputs the third clock as the sampling clock for the other channel;

40 and the control means includes arithmetic means which compares the decision errors respectively obtained from the sampled signals in the in-phase and quadrature channels, and on this basis calculates the amount of phase shift of the phase shift means.

45 18. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
45 timing for sampling, in the main signal lines, a baseband signal obtained by quasi-coherent or coherent detection; and
control means for controlling the amount of phase shift of the phase shift means on the basis of the decision errors of the phase components of the sampled signals obtained by sampling the baseband signal, or on the basis of the decision errors of the signal points of the sampled signals;

50 wherein there is provided:
sampling clock generating means which generates a second clock which alternately has a leading edge or trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point of the first clock by the same timing difference δt ; and

55 sampling means which uses this second clock to sample the baseband signal in separate lines from the main signal lines;
and wherein the control means includes arithmetic means which compares the decision errors obtained from the sampled signals at a leading edge or trailing edge point that leads by δt , with the decision errors obtained

from the sampled signals at the leading edge or trailing edge point that lags by δt , and on this basis calculates the amount of phase shift of the phase shift means.

19. A clock timing recovery circuit comprising:

5

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling, in the main signal lines, a baseband signal obtained by coherent detection; and
control means for controlling the amount of phase shift of this phase shift means on the basis of the decision errors of the signal points of the sampled signals obtained by sampling the baseband signal;

10

wherein there is provided:

sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ; and

15

sampling means which uses the second clock to sample, in separate lines from the main signal lines, the baseband signal in one of the in-phase channel and the quadrature channel, and which uses the third clock to sample the baseband signal in the other channel;

20

and wherein the control means includes arithmetic means which compares the decision errors obtained from the sampled signals of the in-phase and quadrature channels, and on this basis calculates the amount of phase shift of the phase shift means.

20. A clock timing recovery circuit comprising:

25

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal; and
control means for controlling the amount of phase shift of the phase shift means on the basis of the amplitude of the sampled signals obtained by sampling a clock timing recovery signal contained in the baseband signal;
wherein there is provided sampling clock generating means which generates and outputs as the sampling clock for the main signal lines, a second clock which alternately has a leading edge or trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point of the first clock by the same timing difference δt ; and

30

35

the control means includes arithmetic means which compares, in respect of the sampled signals obtained by sampling using this sampling clock, the amplitude of the sampled signal at the leading edge or trailing edge point that leads by δt , and the amplitude of the sampled signal at the leading edge or trailing edge point that lags by δt , and on the basis of the result of this comparison, calculates the amount of phase shift of the phase shift means.

40

21. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock timing for sampling the baseband signal obtained by detection of the received signal; and
control means for controlling the amount of phase shift of the phase shift means on the basis of the amplitude of the sampled signals obtained by sampling a clock timing recovery signal contained in the baseband signal;
wherein there is provided sampling clock generating means which generates a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , and which outputs the second clock as the sampling clock for one of the in-phase channel and the quadrature channel in the main signal lines, and outputs the third clock as the sampling clock for the other channel;

45

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and the control means includes arithmetic means which compares the amplitudes of the sampled signals in the in-phase and quadrature channels, and on the basis of the result of this comparison, calculates the amount of phase shift of the phase shift means.

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22. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;
 phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
 timing for sampling, in the main signal lines, the baseband signal obtained by detection of the received signal;
 and

5 control means for controlling the amount of phase shift of the phase shift means on the basis of the amplitude
 of the sampled signals obtained by sampling a clock timing recovery signal contained in the baseband signal;
 wherein there is provided:

sampling clock generating means which generates a second clock which alternately has a leading edge or
 trailing edge point which leads a leading edge or trailing edge point of the first clock by a predefined timing
 10 difference δt , and a leading edge or trailing edge point which lags behind a leading edge or trailing edge point
 of the first clock by the same timing difference δt ; and

sampling means which uses this second clock to sample the baseband signal in separate lines from the main
 signal lines;

and wherein the control means includes arithmetic means which compares, in respect of the sampled signals
 15 obtained by the sampling means, the amplitude of the sampled signal at a leading edge point or trailing edge
 point which leads by δt , and the amplitude of the sampled signal at a leading edge point or trailing edge
 point which lags by δt , and on the basis of the result of this comparison, calculates the amount of phase shift of the
 phase shift means.

20 23. A clock timing recovery circuit comprising:

clock generating means for generating a system clock which repeats with a fixed period;

phase shift means which outputs a first clock, phase-shifted with respect to the system clock, as the clock
 timing for sampling, in the main signal lines, the baseband signal obtained by detection of the received signal;
 25 and

control means for controlling the amount of phase shift of the phase shift means on the basis of the amplitude
 of the sampled signals obtained by sampling a clock timing recovery signal contained in the baseband signal;
 wherein there is provided:

sampling clock generating means which generates a second clock with leading or trailing edge points which
 30 lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock
 with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the
 same timing difference δt ; and

sampling means which uses the second clock to sample, in separate lines from the main signal lines, the
 baseband signal in one of the in-phase channel and the quadrature channel, and which uses the third clock
 35 to sample the baseband signal in the other channel;

and wherein the control means includes arithmetic means which compares the amplitudes of the sampled
 signals in the in-phase and quadrature channels, and on the basis of the results of this comparison, calculates
 the amount of phase shift of the phase shift means.

40 24. A clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband
 signal obtained by detection of the received signal, the clock timing for sampling the baseband signal that follows
 this signal for clock timing recovery;

said method comprising:

45 forming, as the sampling clock, a clock whereof the phase of its n -th leading edge point or trailing edge point
 ($n = 1, 2, 3, \dots$) from the origin, where one leading edge point or trailing edge point of a system clock which
 repeats with a fixed period is taken as the origin, is shifted by $n \times \Delta t$ relative to the phase of the system clock
 (where Δt is a predefined amount of phase shift);

sampling the signal for clock timing recovery using this sampling clock;

50 estimating, from the sampled signals obtained by this sampling, the phase difference between the phase of
 the system clock and the clock timing at which the bit error rate is minimum; and

recovering the clock timing for sampling the baseband signal that follows the signal for clock timing recovery,
 by causing the phase of the system clock to shift by the estimated amount of phase difference.

55 25. A clock timing recovery method for recovering clock timing on the basis of the decision errors of sampled signals
 obtained by sampling a baseband signal;

said method comprising:

generating, from a first clock obtained by phase shifting a system clock which repeats with a fixed period, a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , said second and third clocks serving as sampling clocks for the main signal lines;
 obtaining decision errors from the sampled signals obtained by using these sampling clocks to sample the baseband signal;
 calculating the amount of phase shift to be applied to the first clock on the basis of the result of comparing the decision errors obtained from the sampled signals at the leading edge or trailing edge point of the second clock, with the decision errors obtained from the sampled signals at the leading edge or trailing edge point of the third clock; and
 shifting the phase of the system clock on the basis of this amount of phase shift.

26. A clock timing recovery method for recovering clock timing on the basis of the decision errors of the sampled signals obtained by sampling a baseband signal;

said method comprising:
 outputting, as the sampling clock for the main signal lines, a first clock obtained by phase shifting a system clock which repeats with a fixed period, and forming a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ;
 obtaining decision errors from the sampled signals obtained using these second and third clocks to sample the baseband signal separately from the main signal lines;
 calculating the amount of phase shift to be applied to the first clock on the basis of the result of comparing the decision errors obtained from the sampled signals at the leading edge or trailing edge point of the second clock, with the decision errors obtained from the sampled signals at the leading edge or trailing edge point of the third clock; and
 shifting the phase of the system clock on the basis of this amount of phase shift.

27. A clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband signal obtained by detection of the received signal, the clock timing required for decoding this baseband signal;

said method comprising:
 forming, from a first clock obtained by phase shifting a system clock which repeats with a fixed period, a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt , these second and third clocks serving as sampling clocks for the main signal lines;
 using these sampling clocks to sample the signal for clock timing recovery;
 comparing, in respect of the sampled signals obtained by this sampling, the amplitude of the sampled signal at the leading edge point or trailing edge point of the second clock, with the amplitude of the sampled signal at the leading edge point or trailing edge point of the third clock;
 calculating the amount of phase shift to be applied to the first clock on the basis of the result of this comparison; and
 recovering the clock timing by shifting the phase of the system clock on the basis of this amount of phase shift.

28. A clock timing recovery method for recovering, from a signal for clock timing recovery contained in the baseband signal obtained by detection of the received signal, the clock timing required for decoding this baseband signal;

said method comprising:
 outputting, as the sampling clock for the main signal lines, a first clock obtained by phase shifting a system clock which repeats with a fixed period, and forming a second clock with leading or trailing edge points which lead the leading or trailing edge points of the first clock by a predefined timing difference δt , and a third clock with leading or trailing edge points which lag behind the leading or trailing edge points of the first clock by the same timing difference δt ;
 using these second and third clocks to sample the signal for clock timing recovery in separate lines from the main signal lines;

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comparing, in respect of the sampled signals obtained by this sampling, the amplitude of the sampled signal at a leading edge point or a trailing edge point of the second clock, with the amplitude of the sampled signal at the leading edge point or trailing edge point of the third clock;
calculating the amount of phase shift to be applied to the first clock on the basis of the results of this comparison;
and
recovering the clock timing by shifting the phase of the system clock on the basis of this amount of phase shift.

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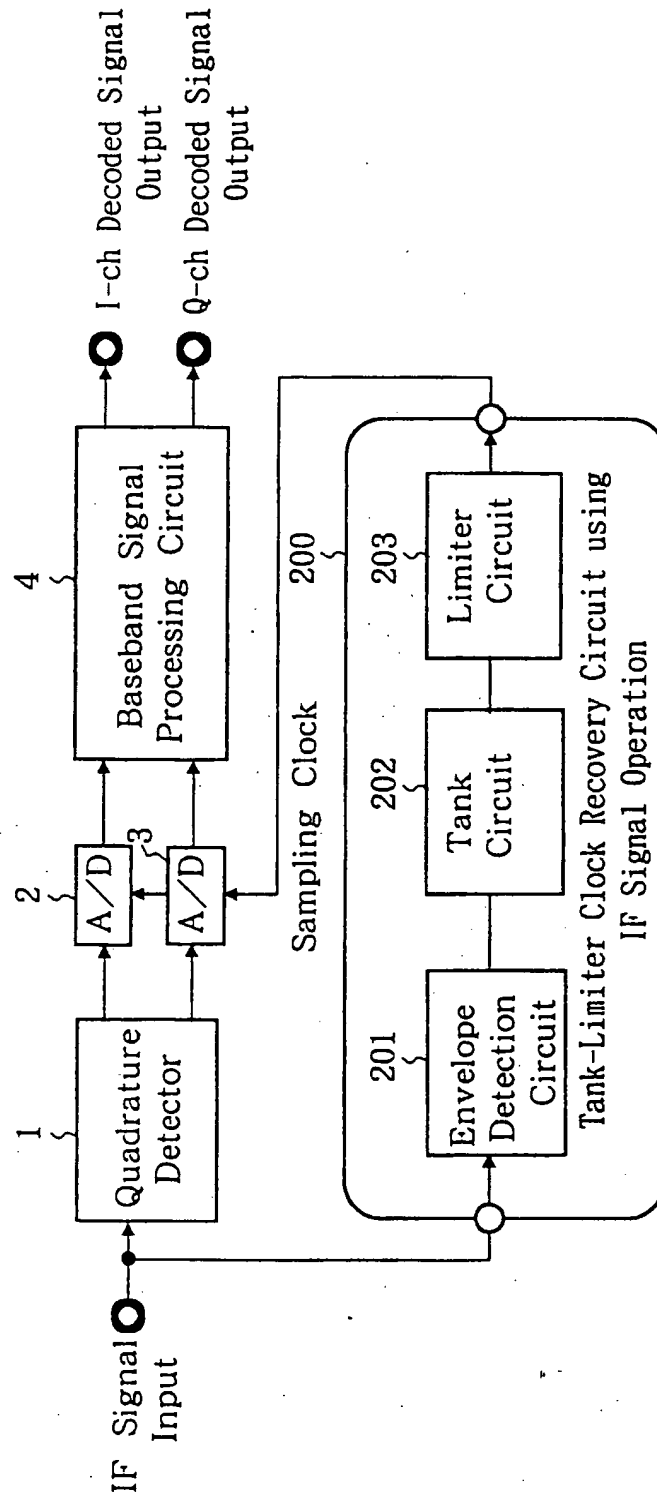
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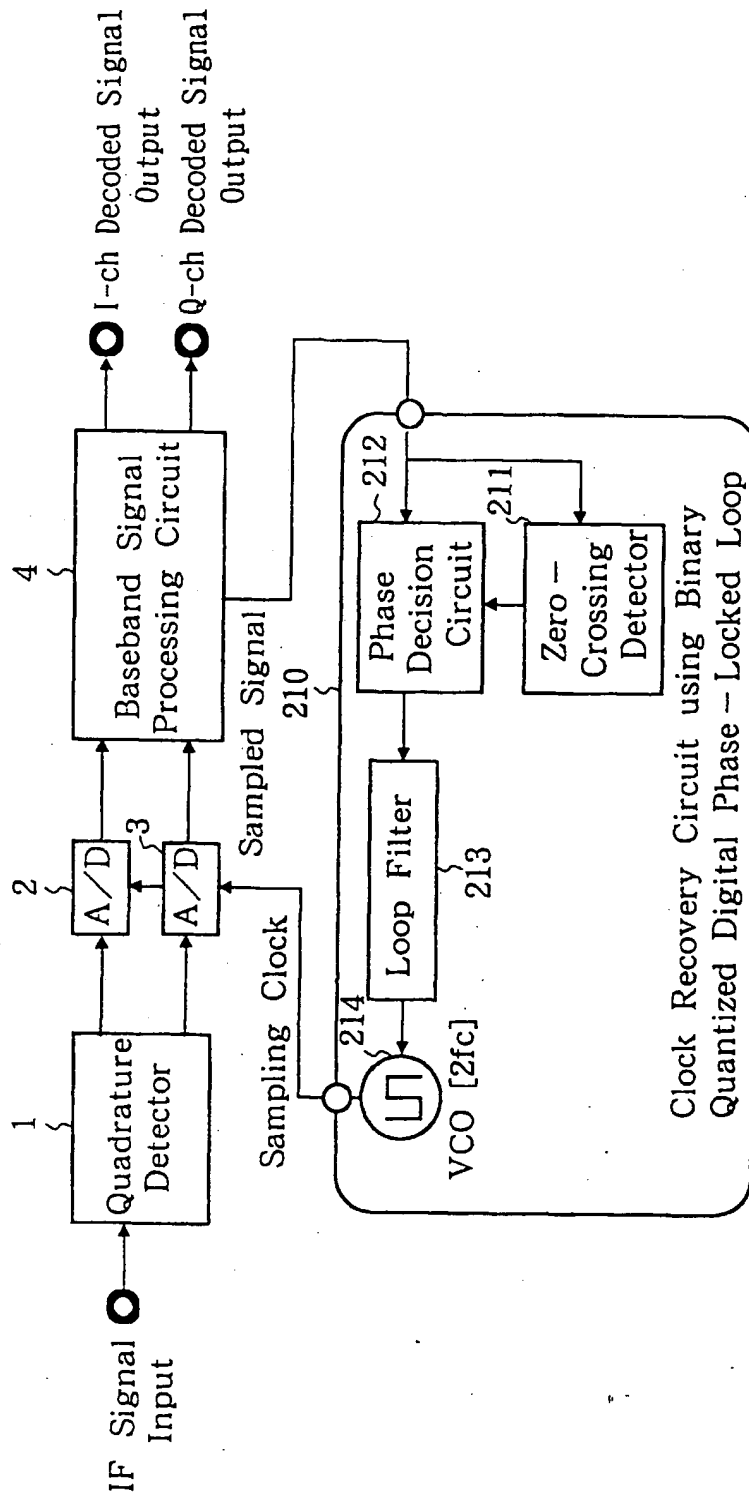
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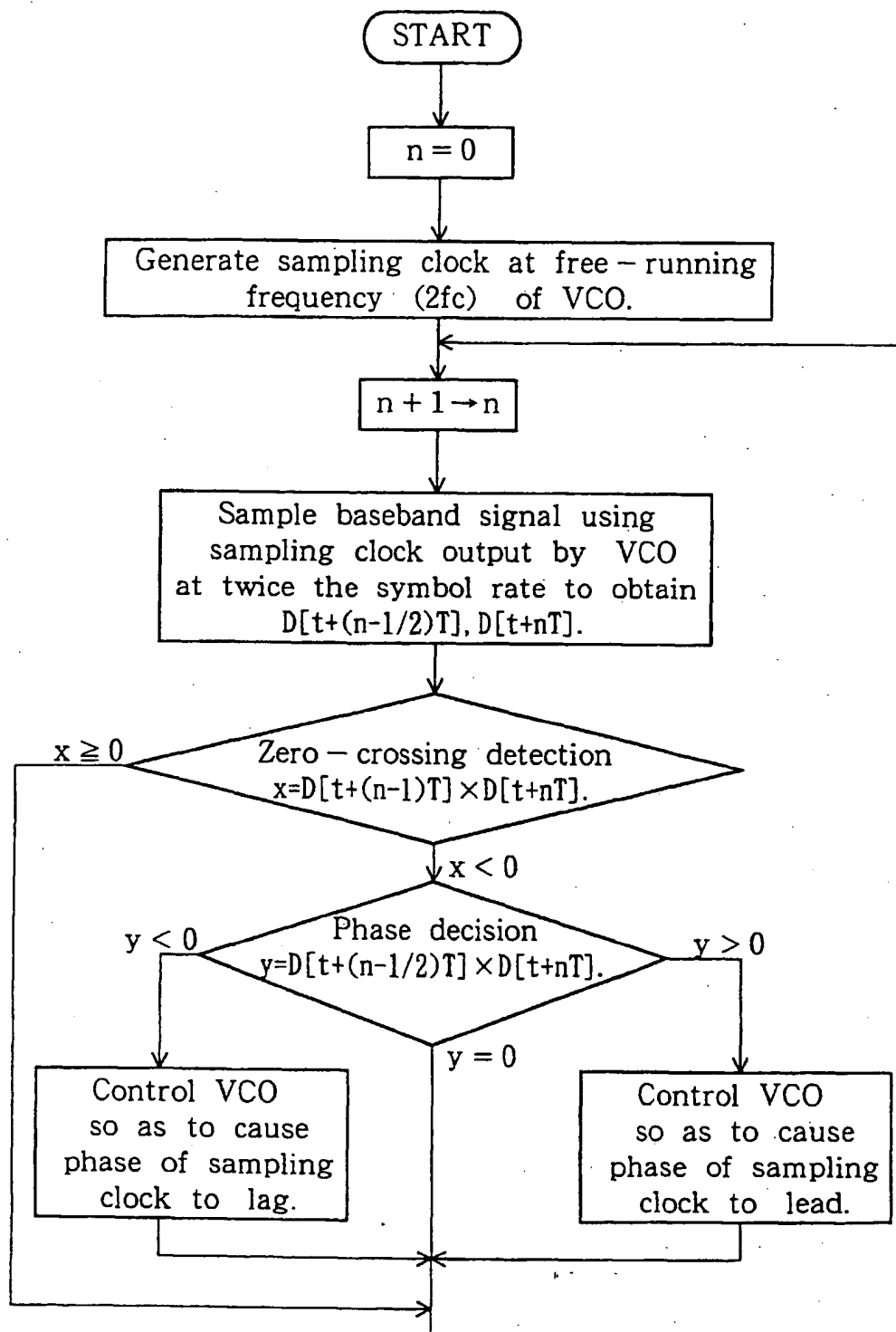


Prior Art
FIG.1



Prior Art

FIG.2



Prior Art
FIG.3

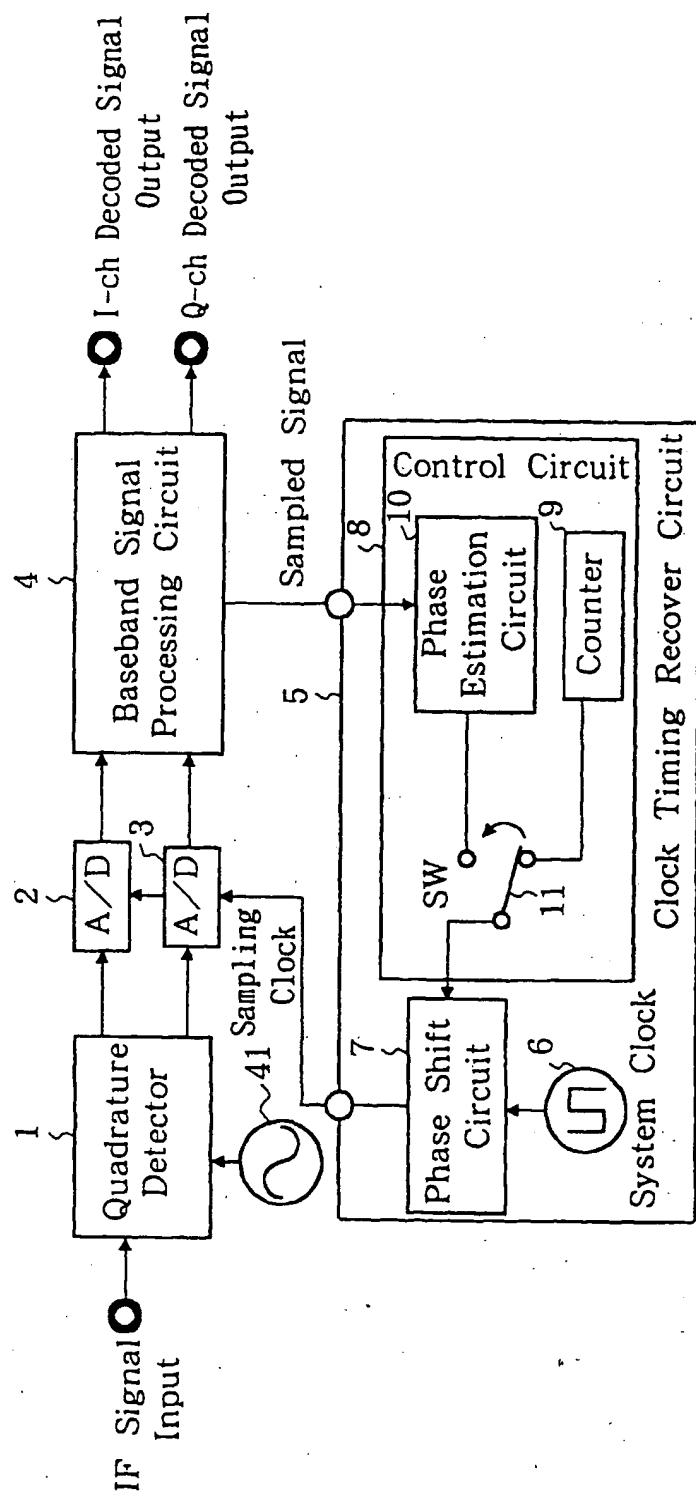


FIG.4

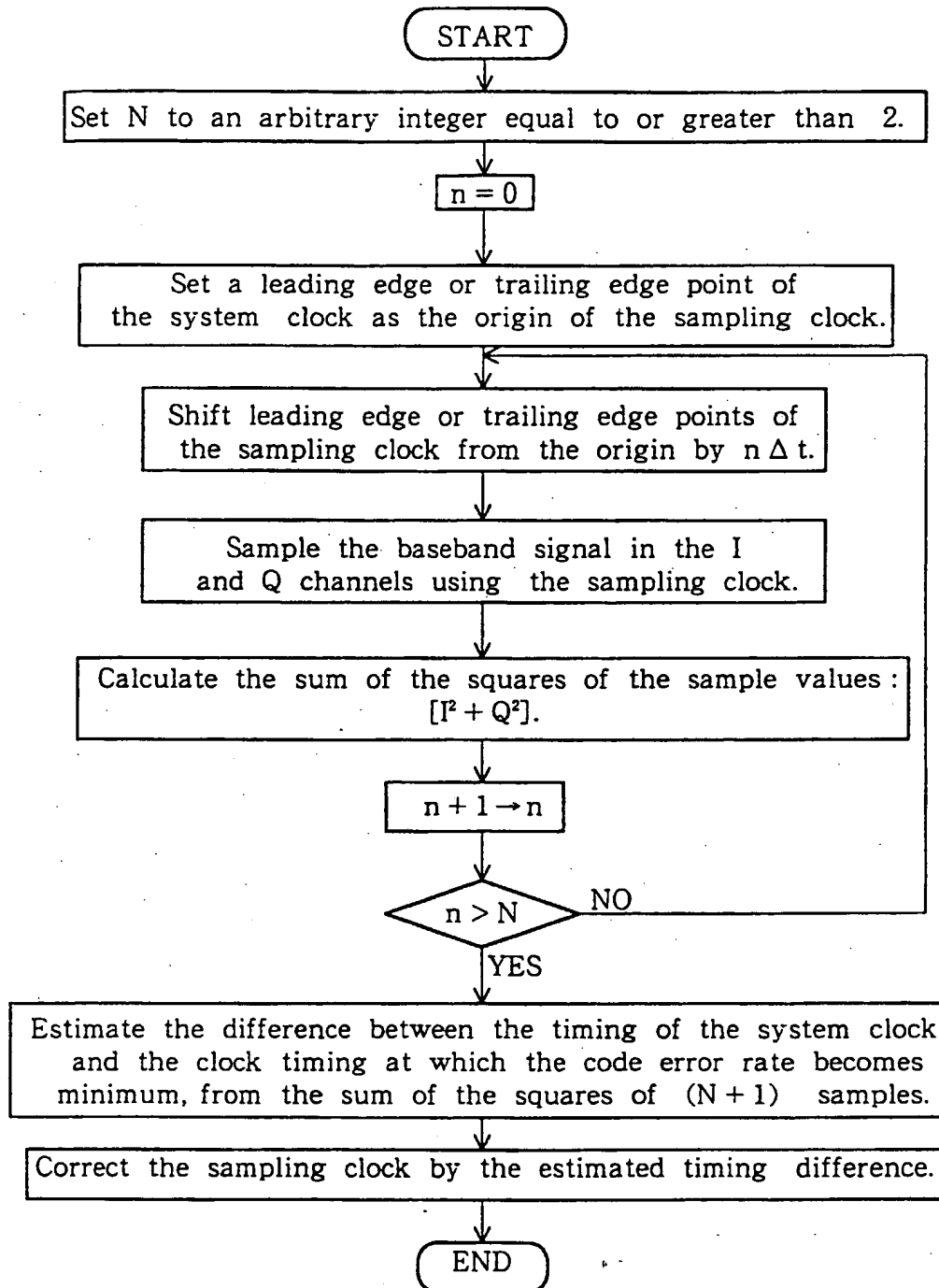
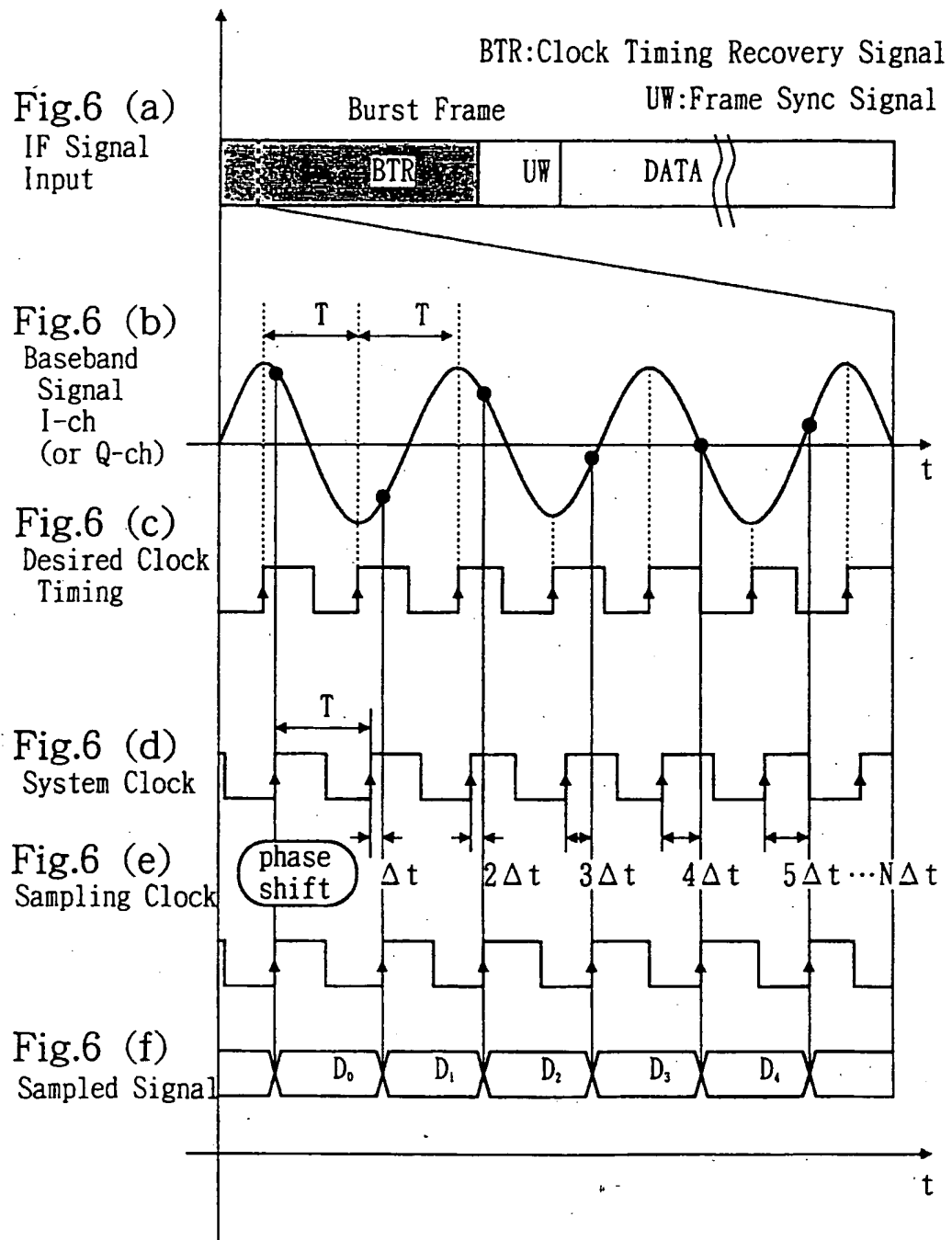


FIG.5



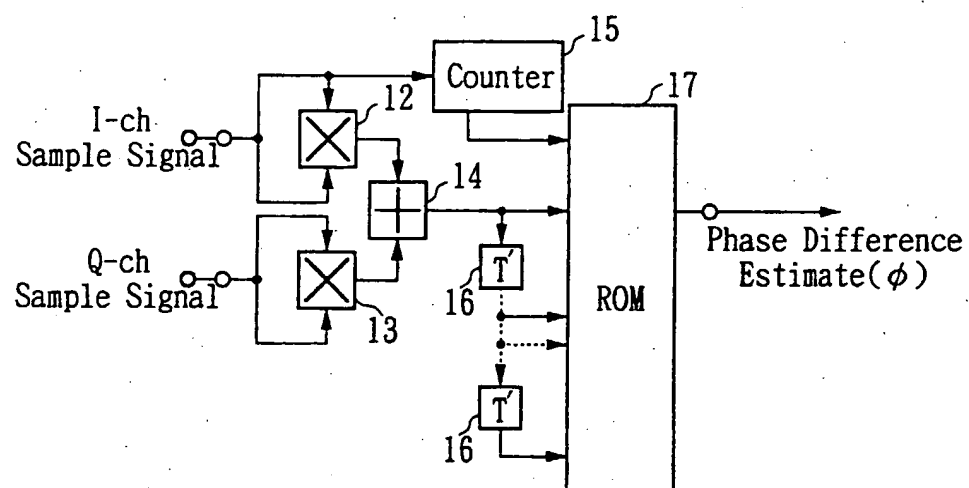
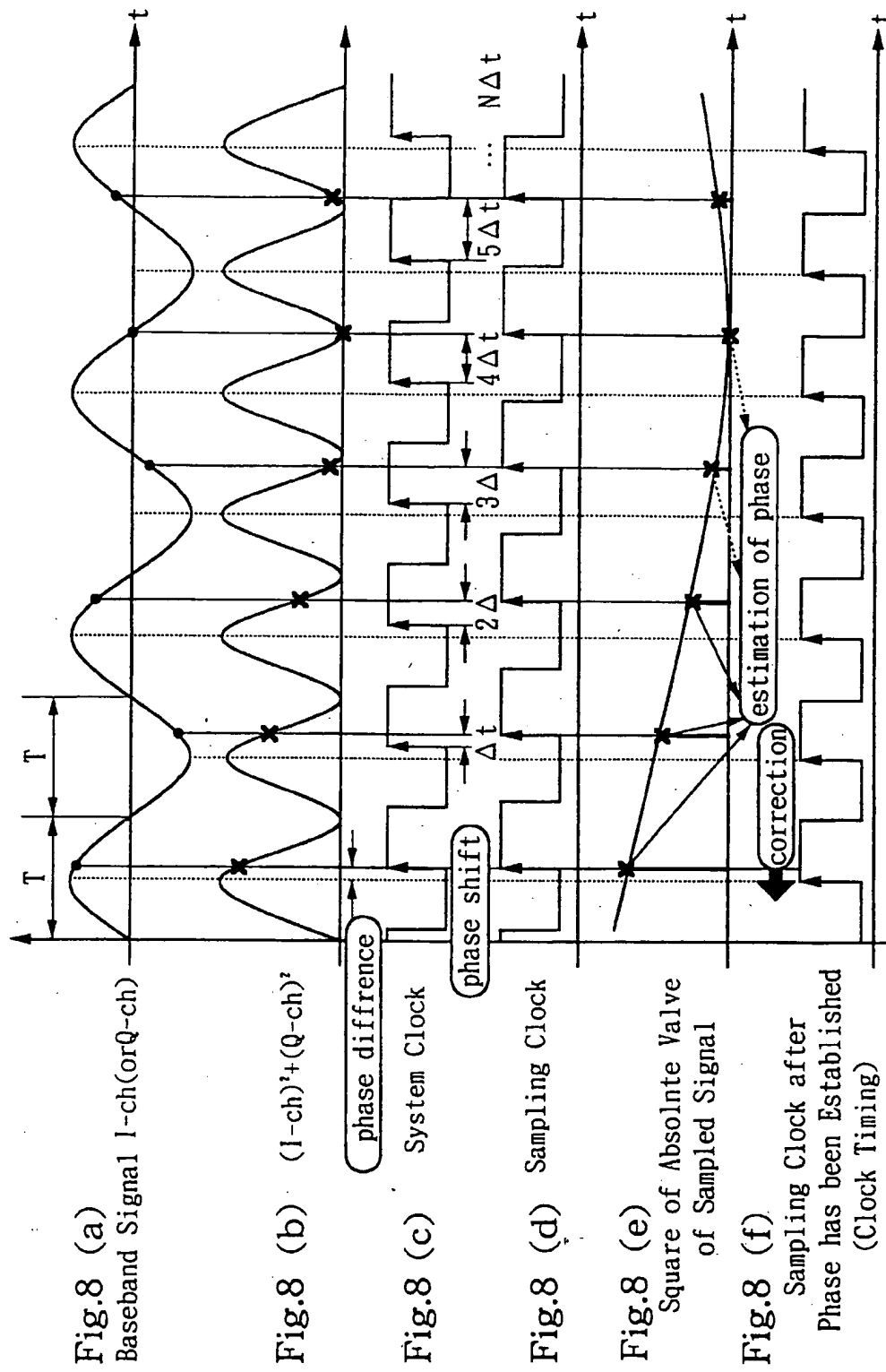


FIG. 7



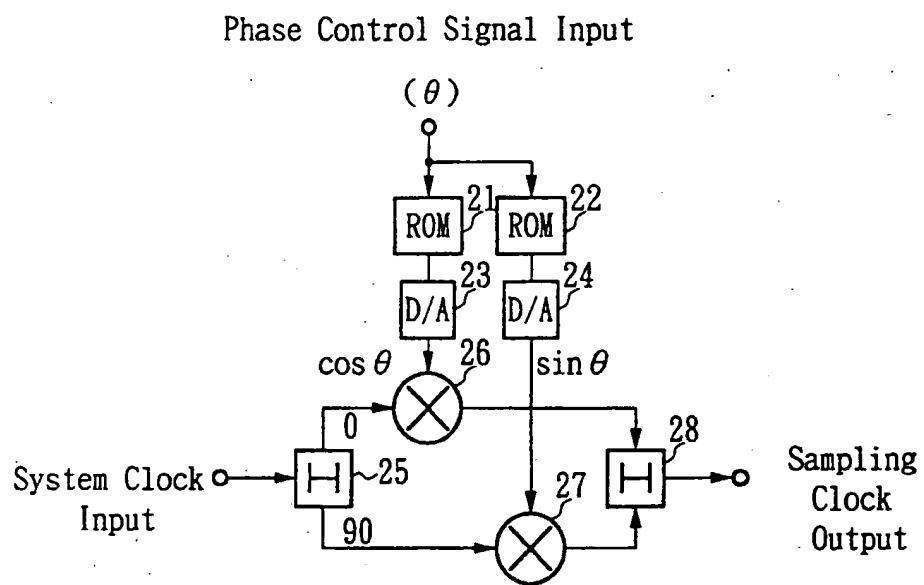
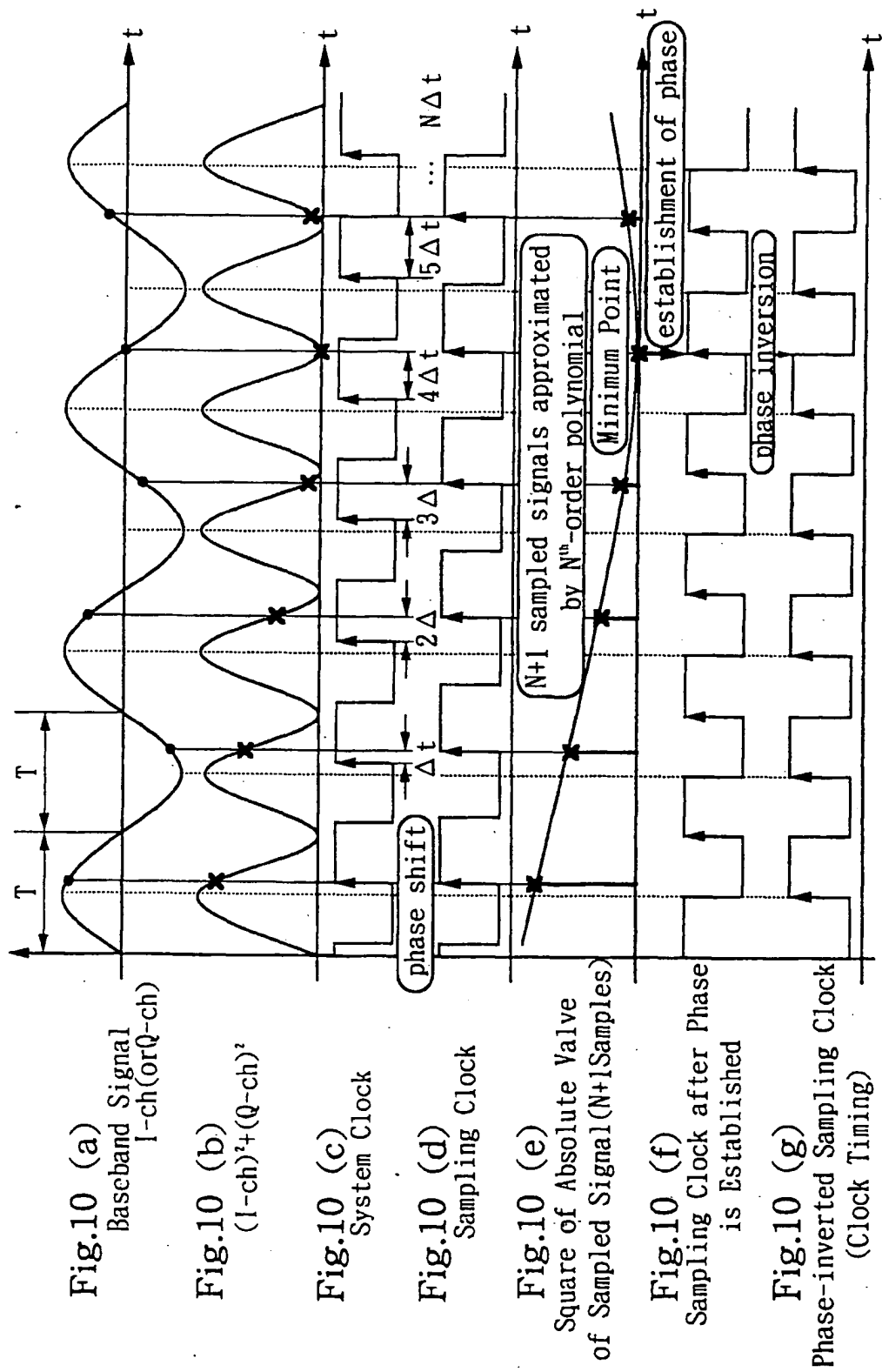


FIG.9



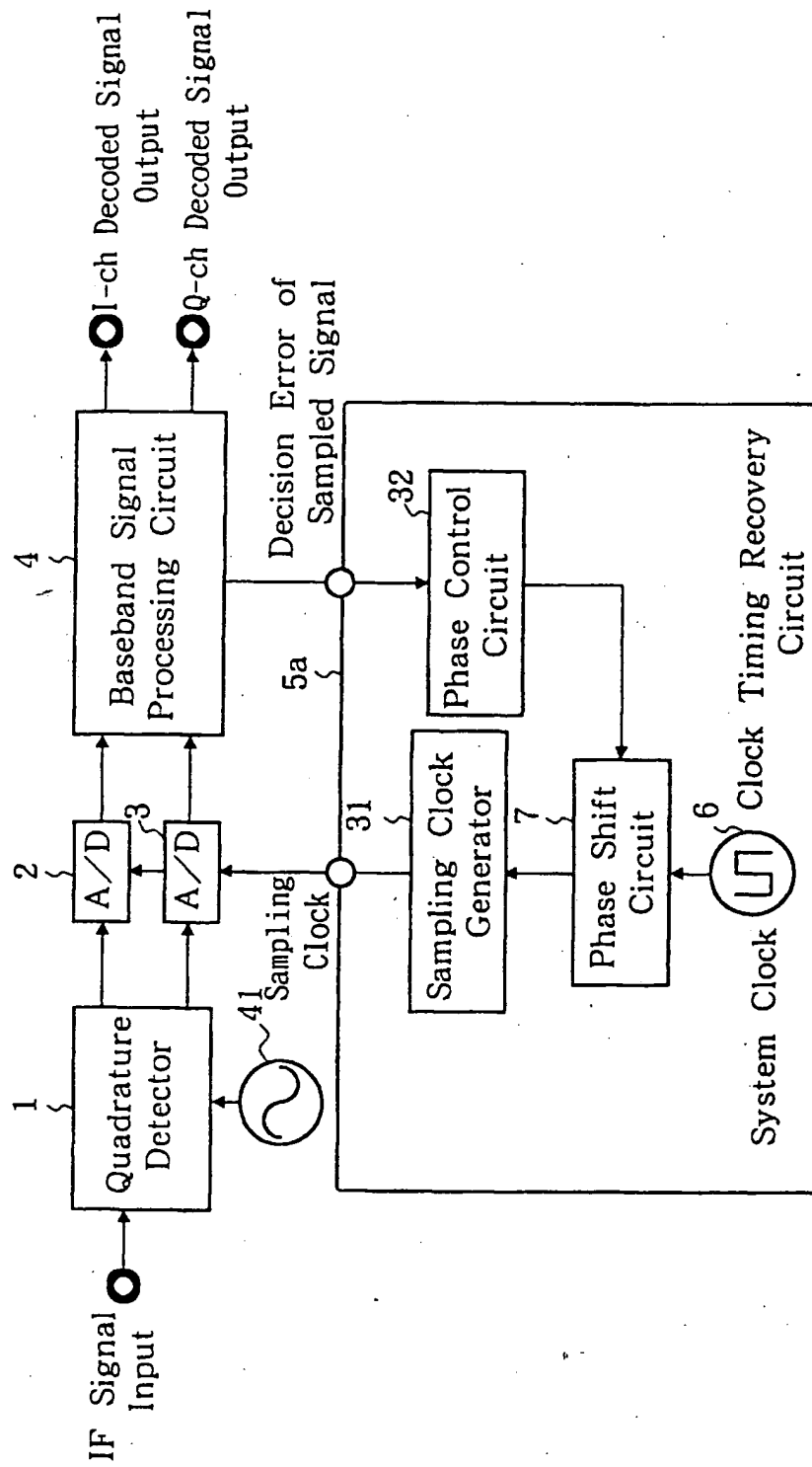


FIG.11

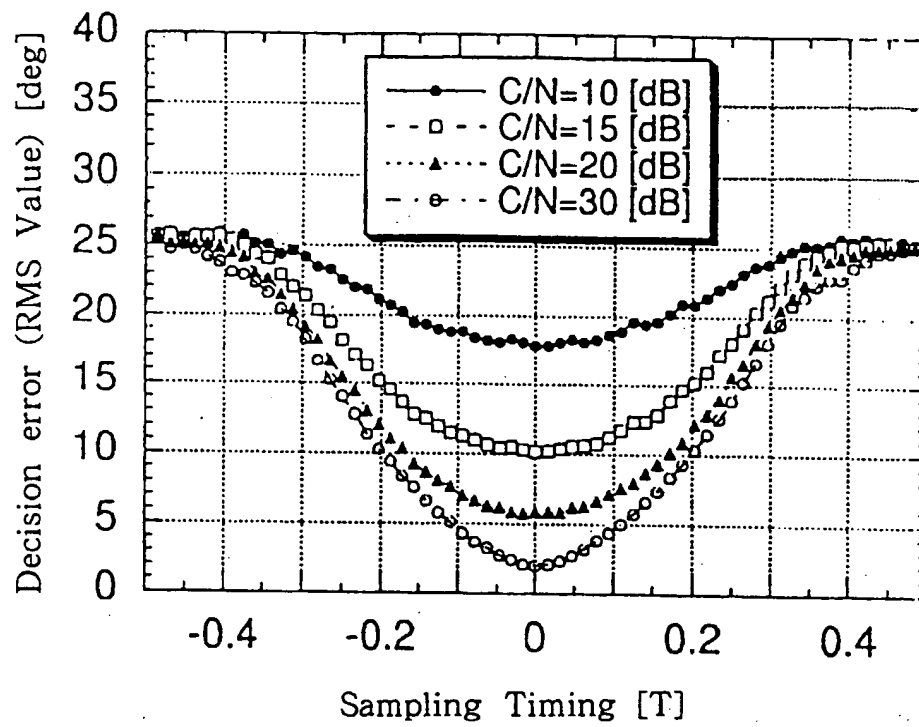
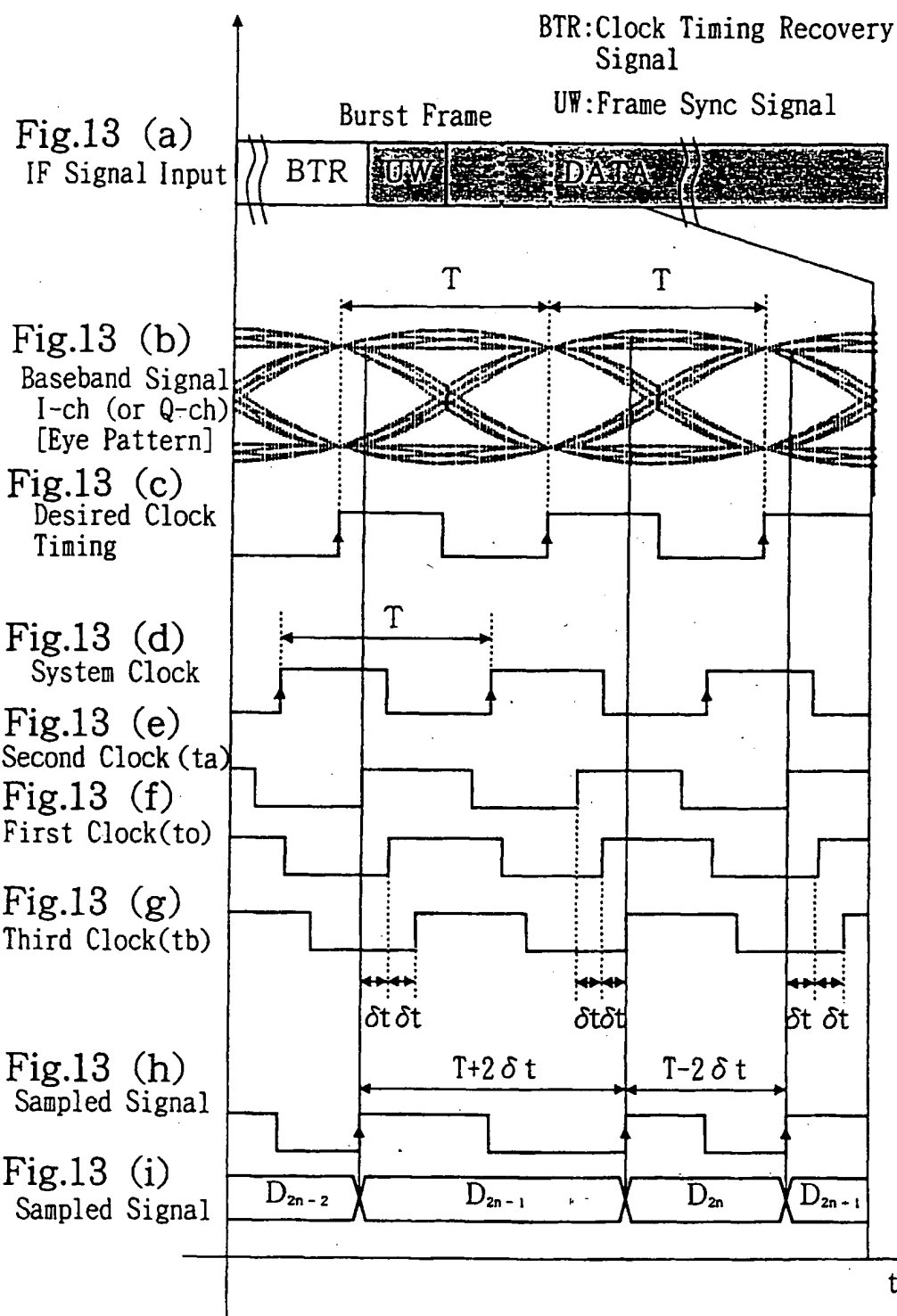


FIG.12



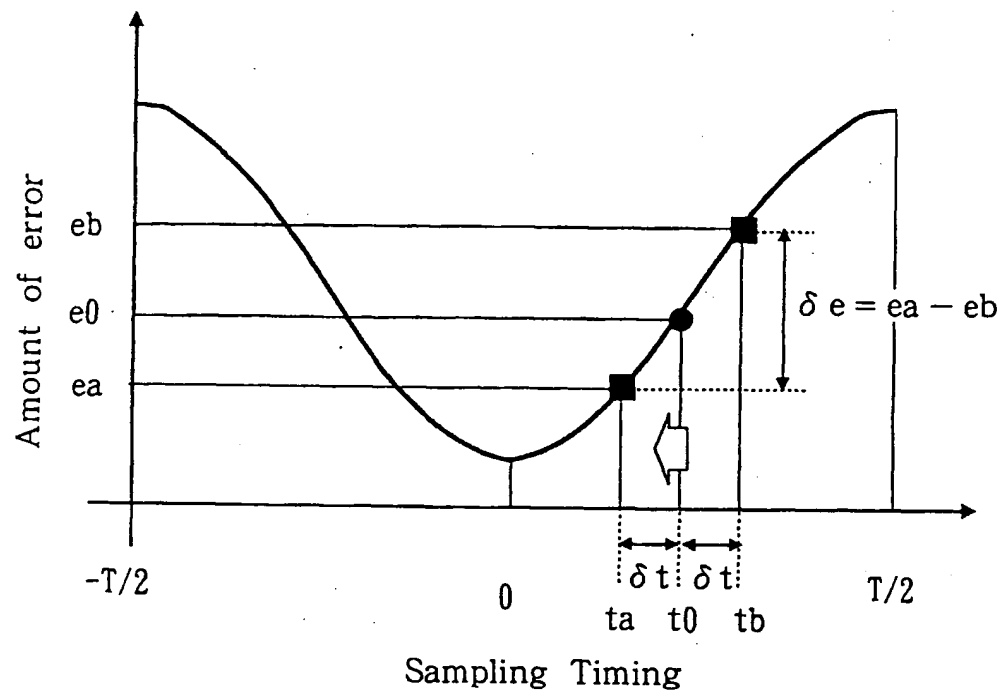


FIG.14

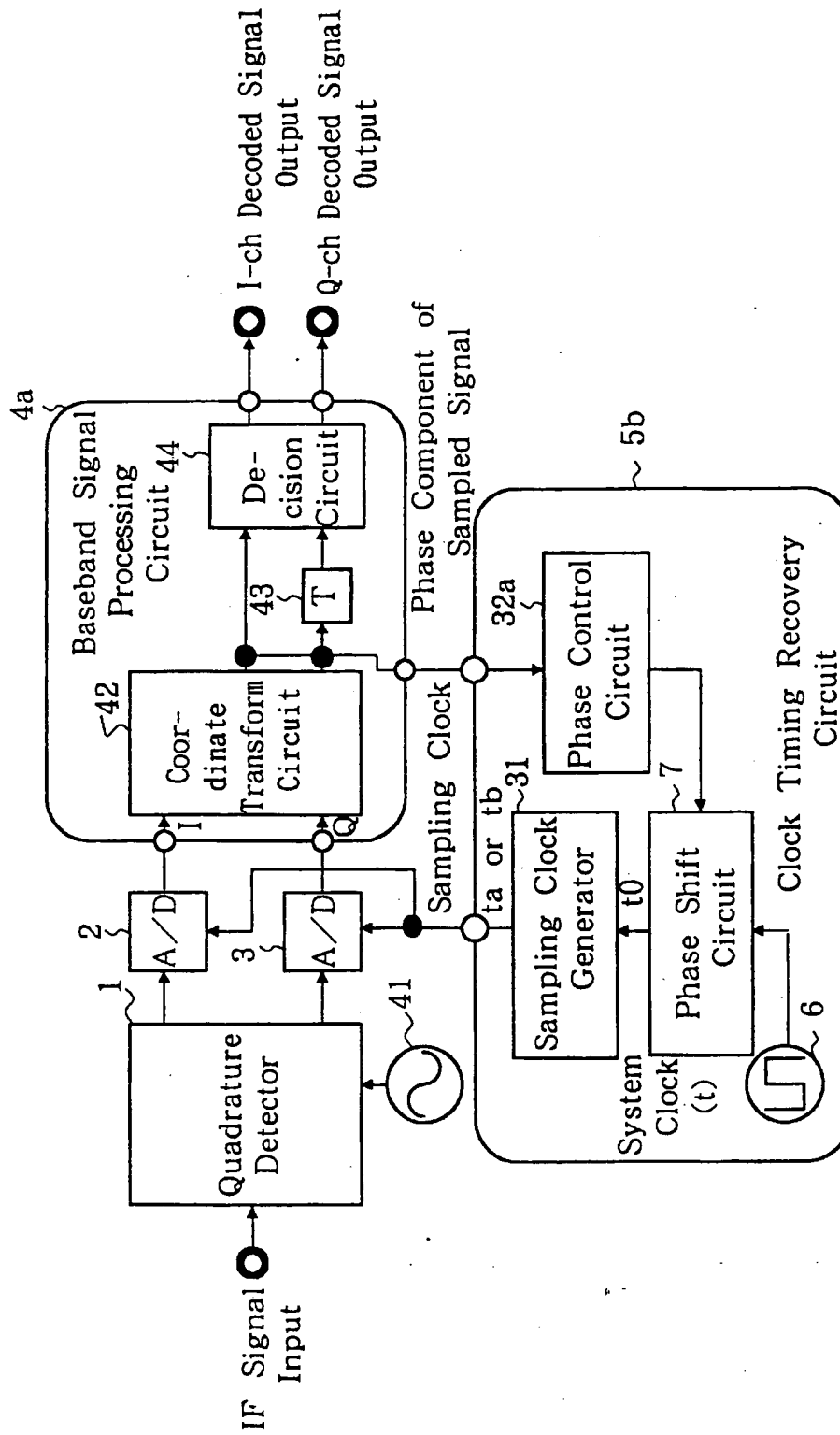


FIG.15

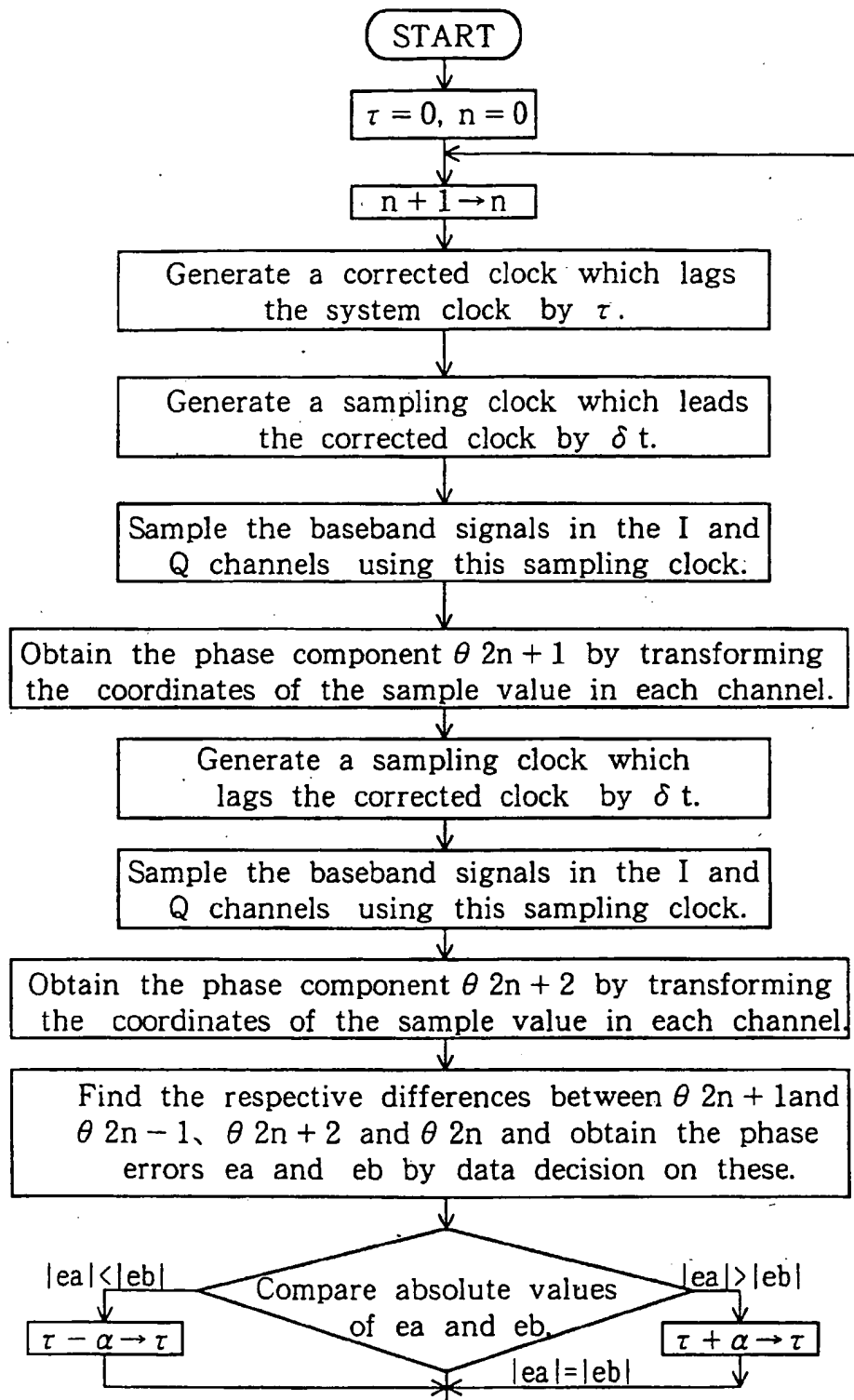


FIG.16

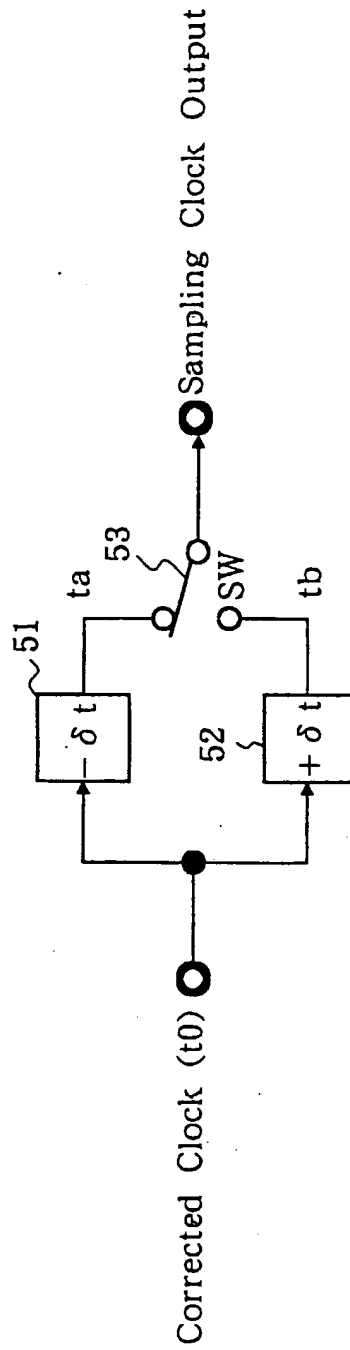


FIG.17

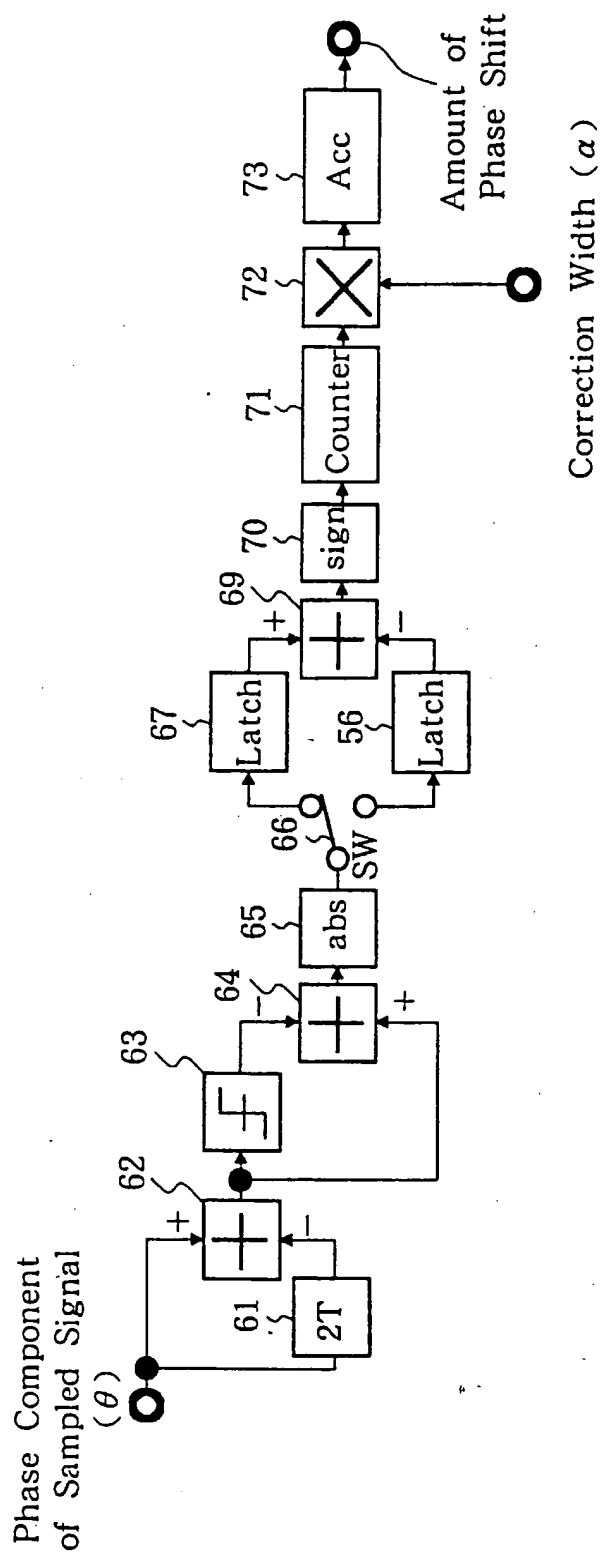


FIG.18

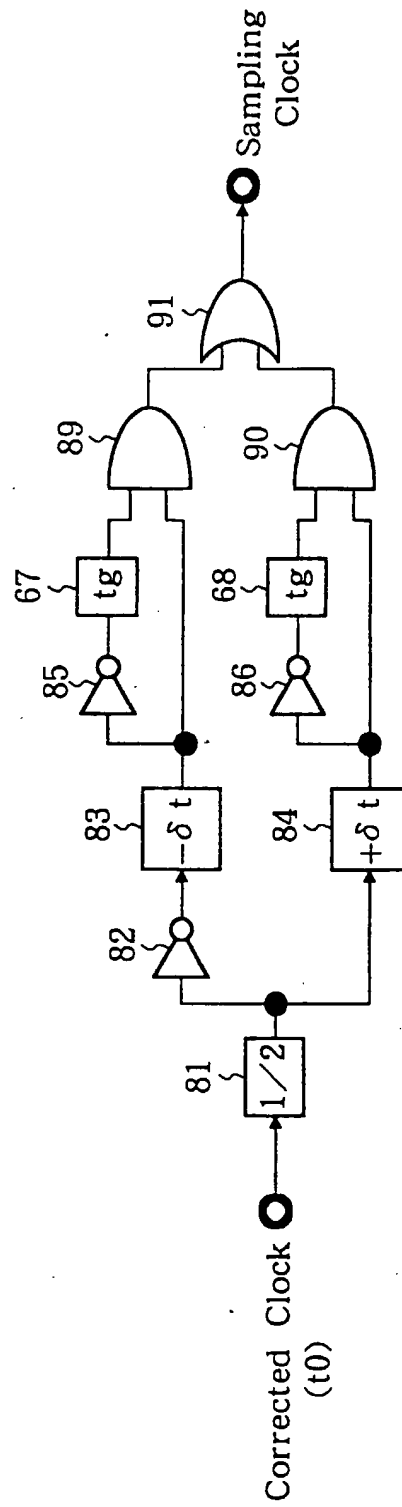


FIG.19

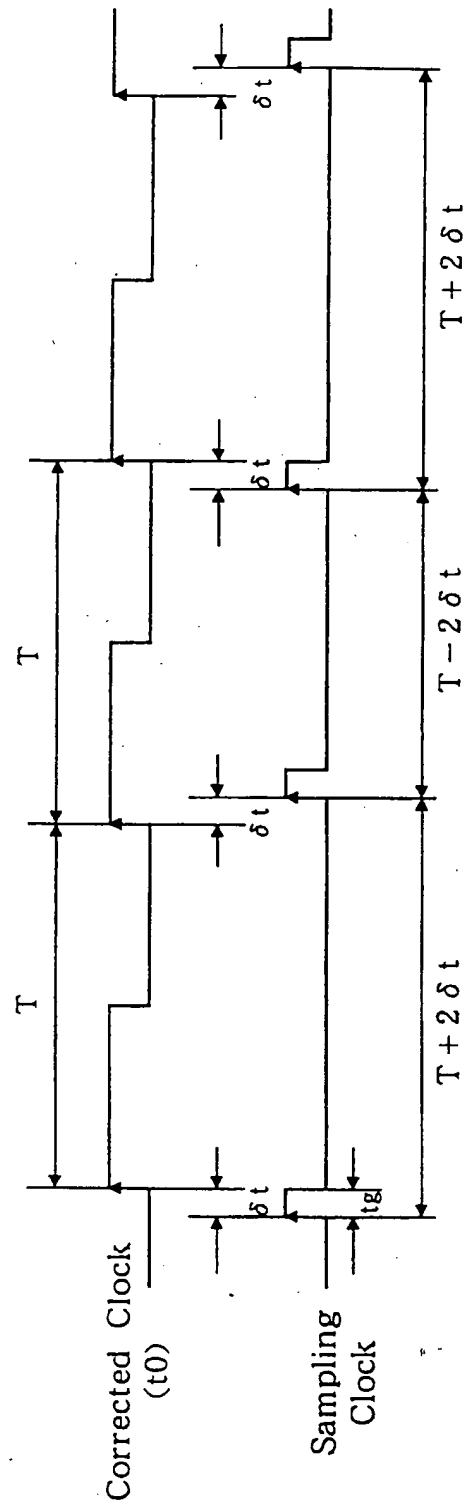


FIG.20

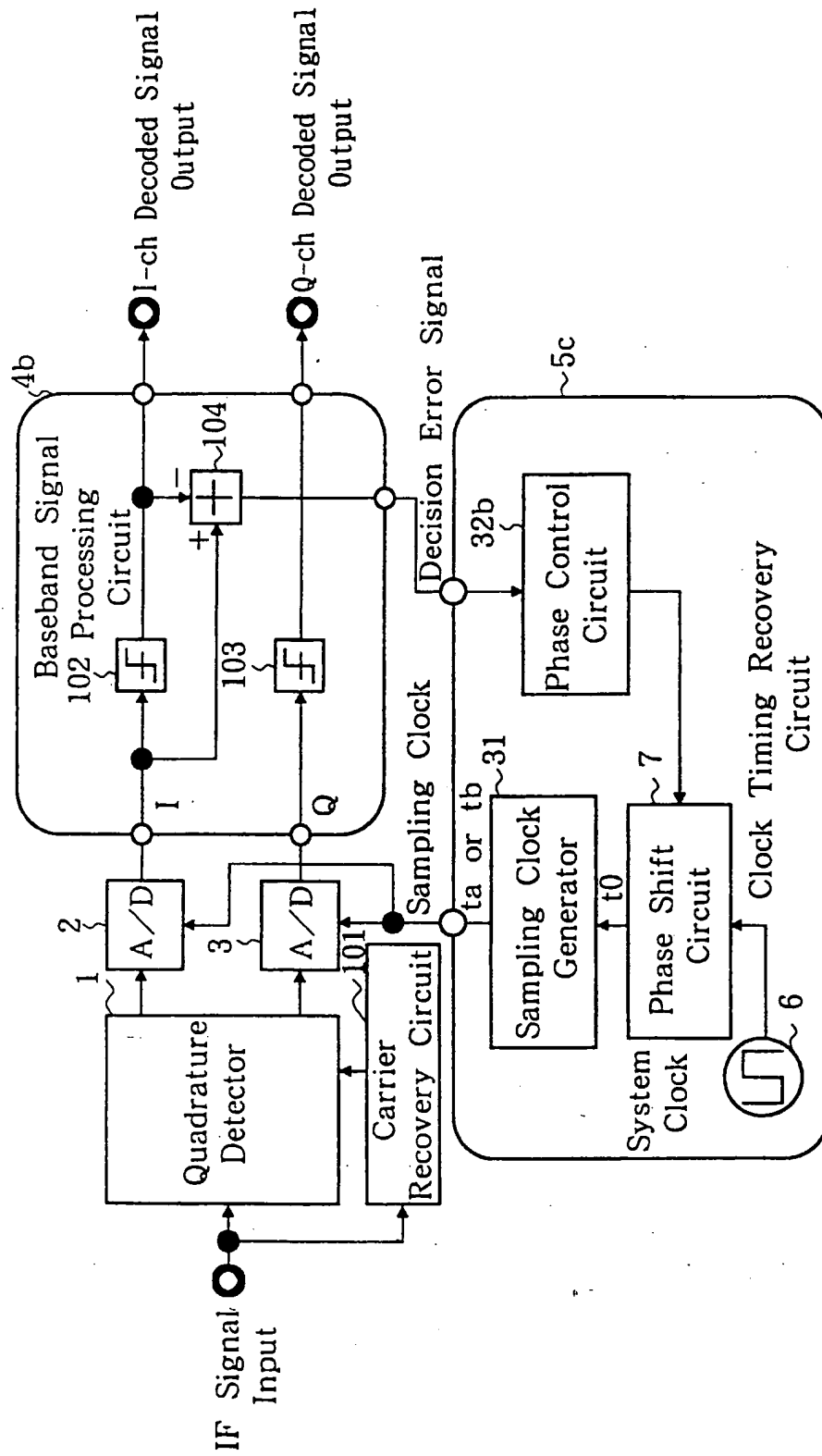


FIG.21

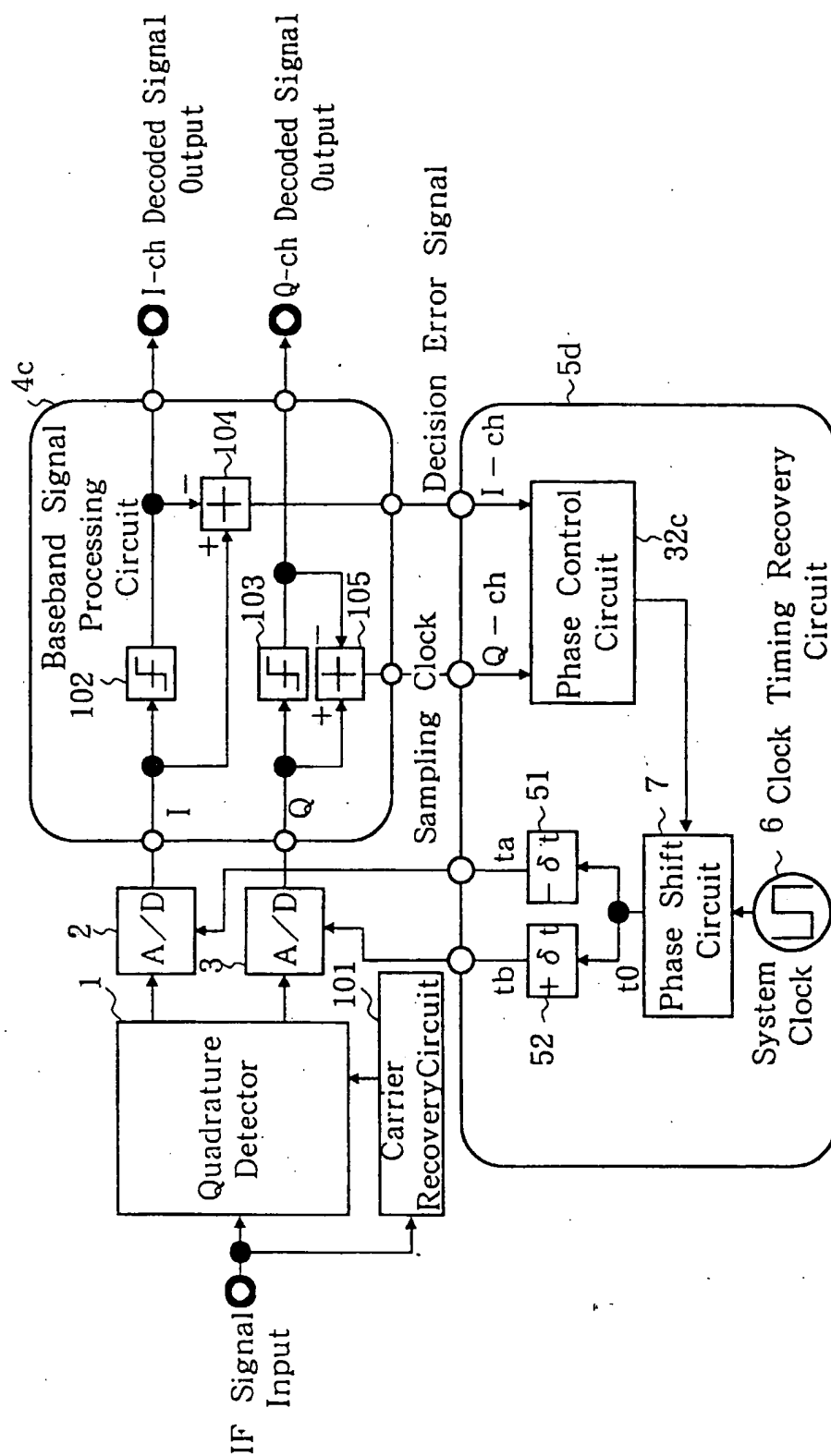


FIG.22

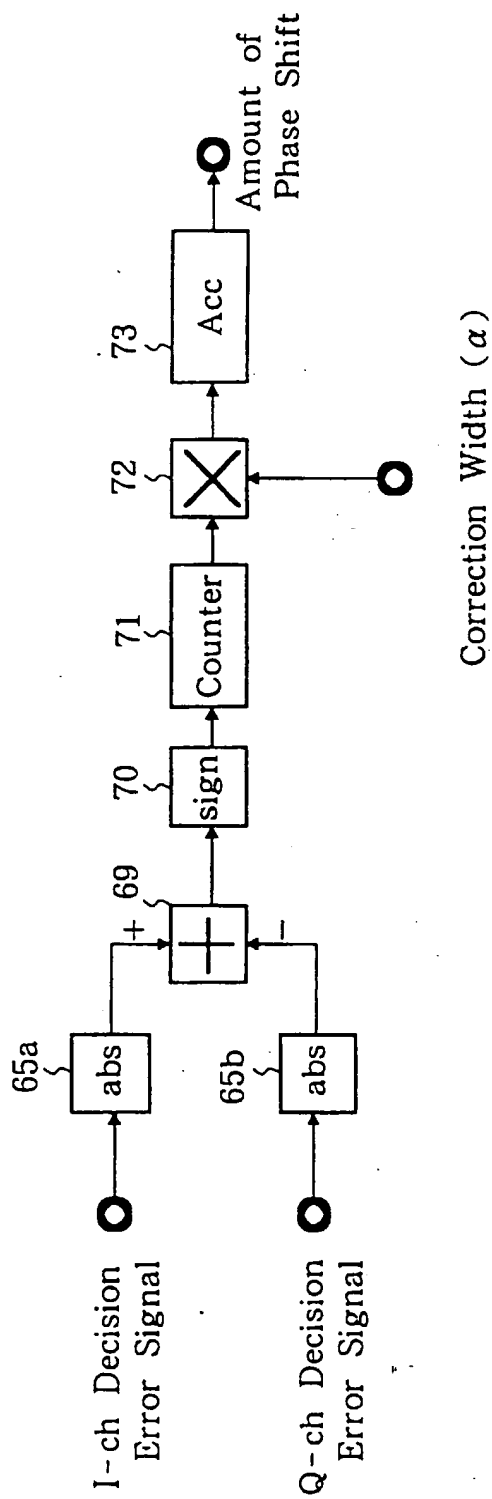


FIG.23

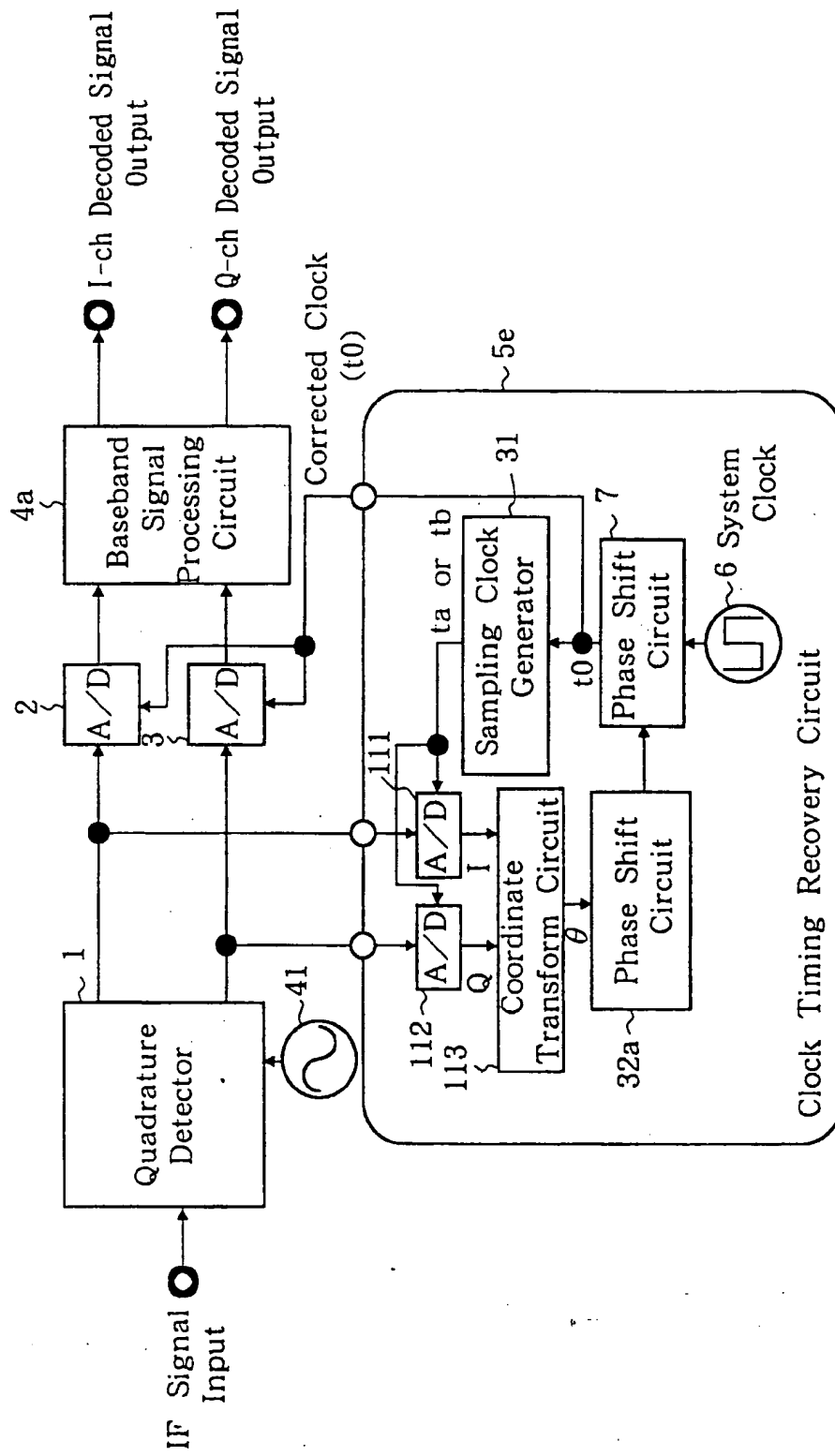


FIG. 24

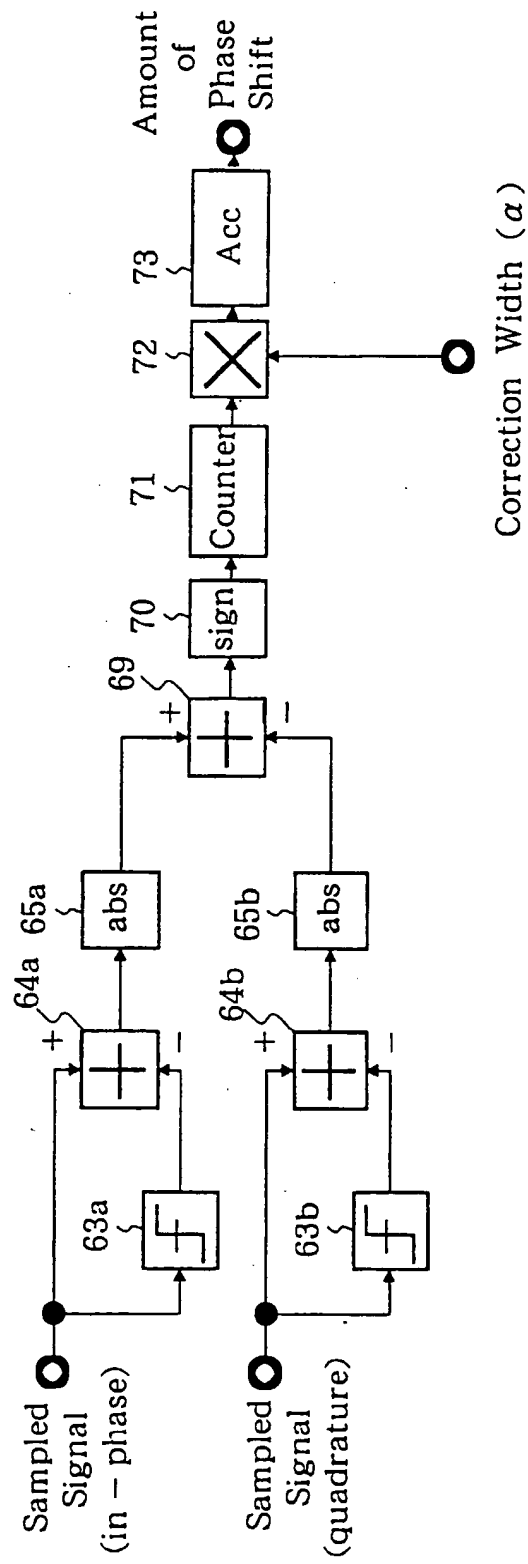


FIG.25

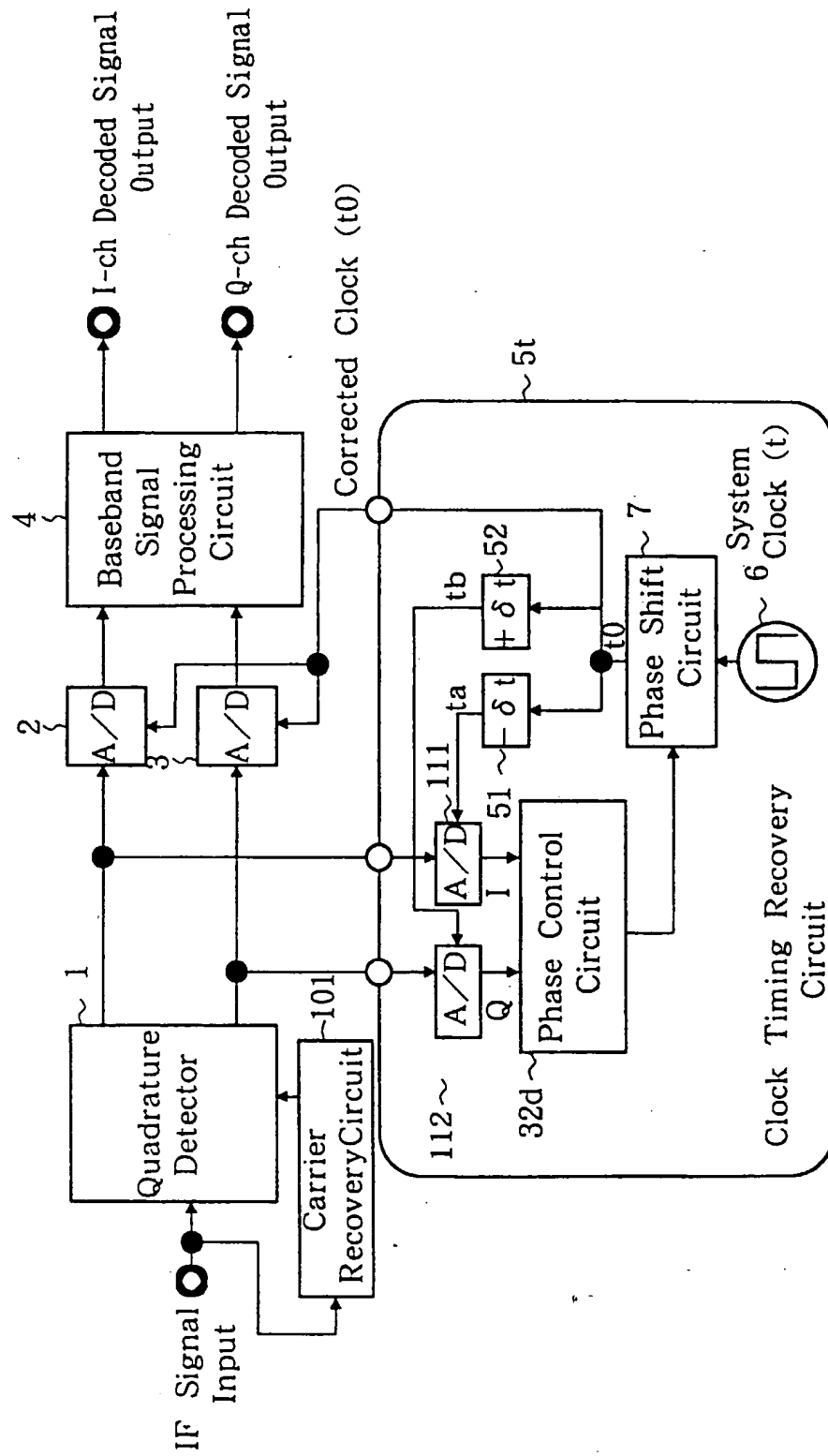


FIG. 26

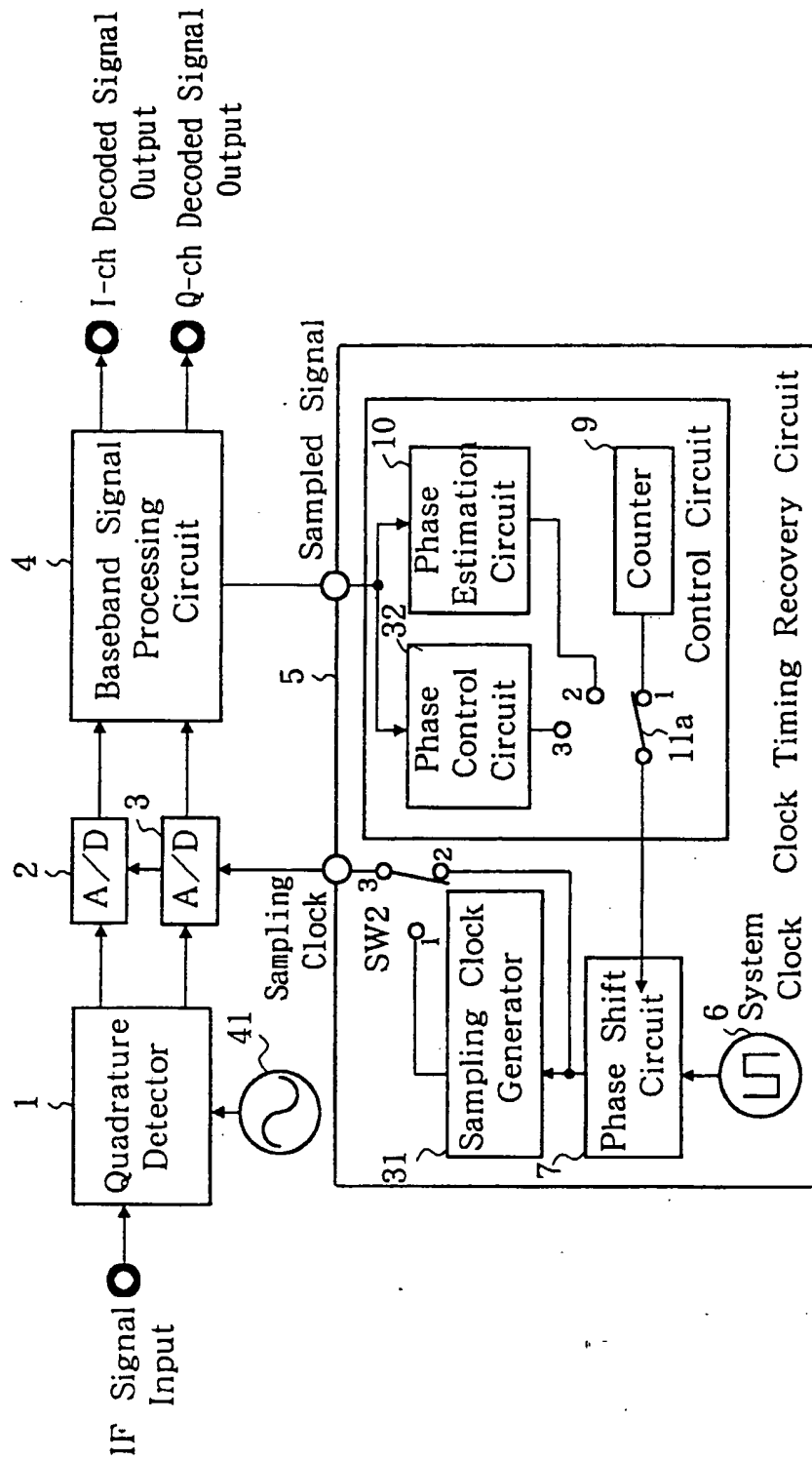


FIG.27

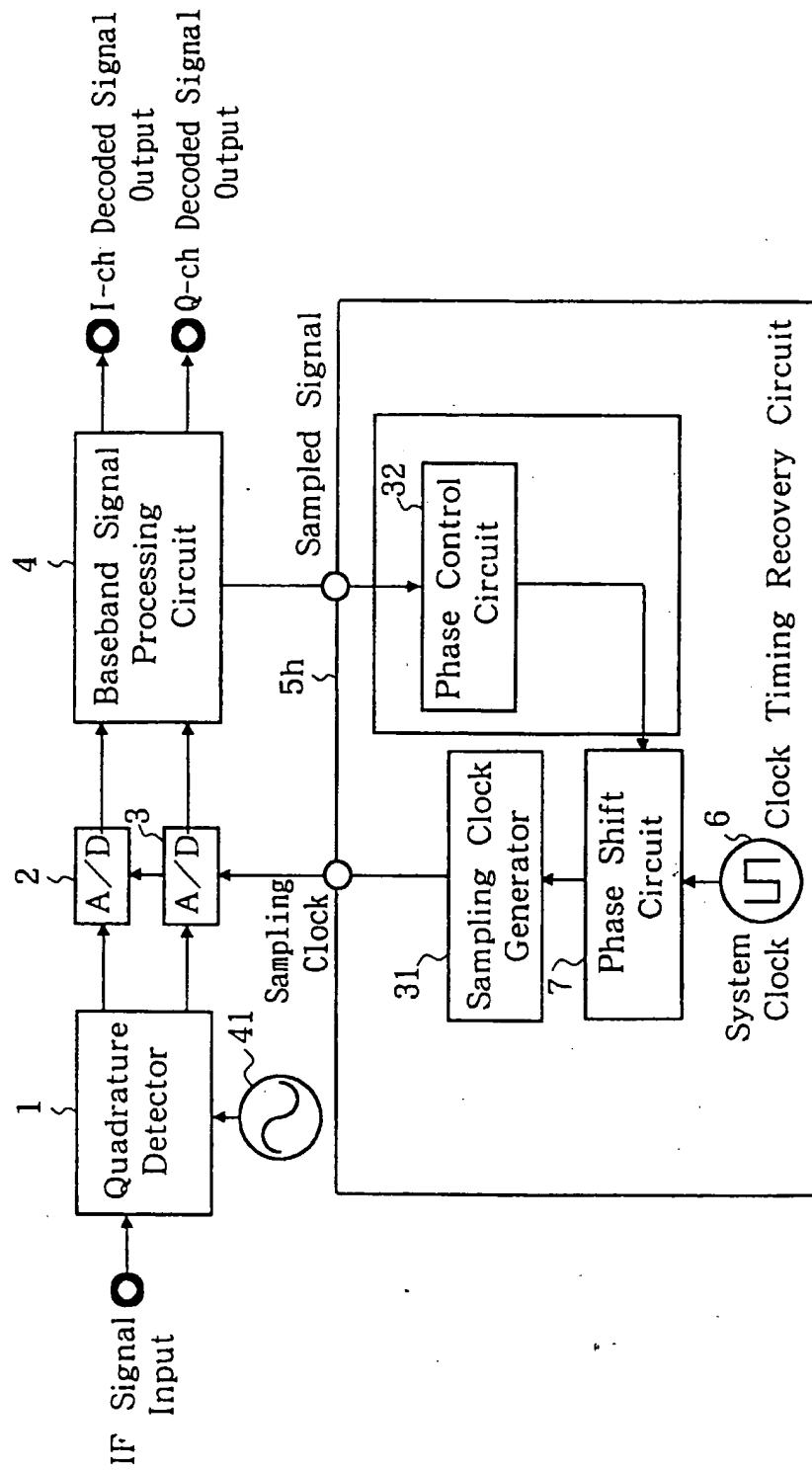


FIG. 28

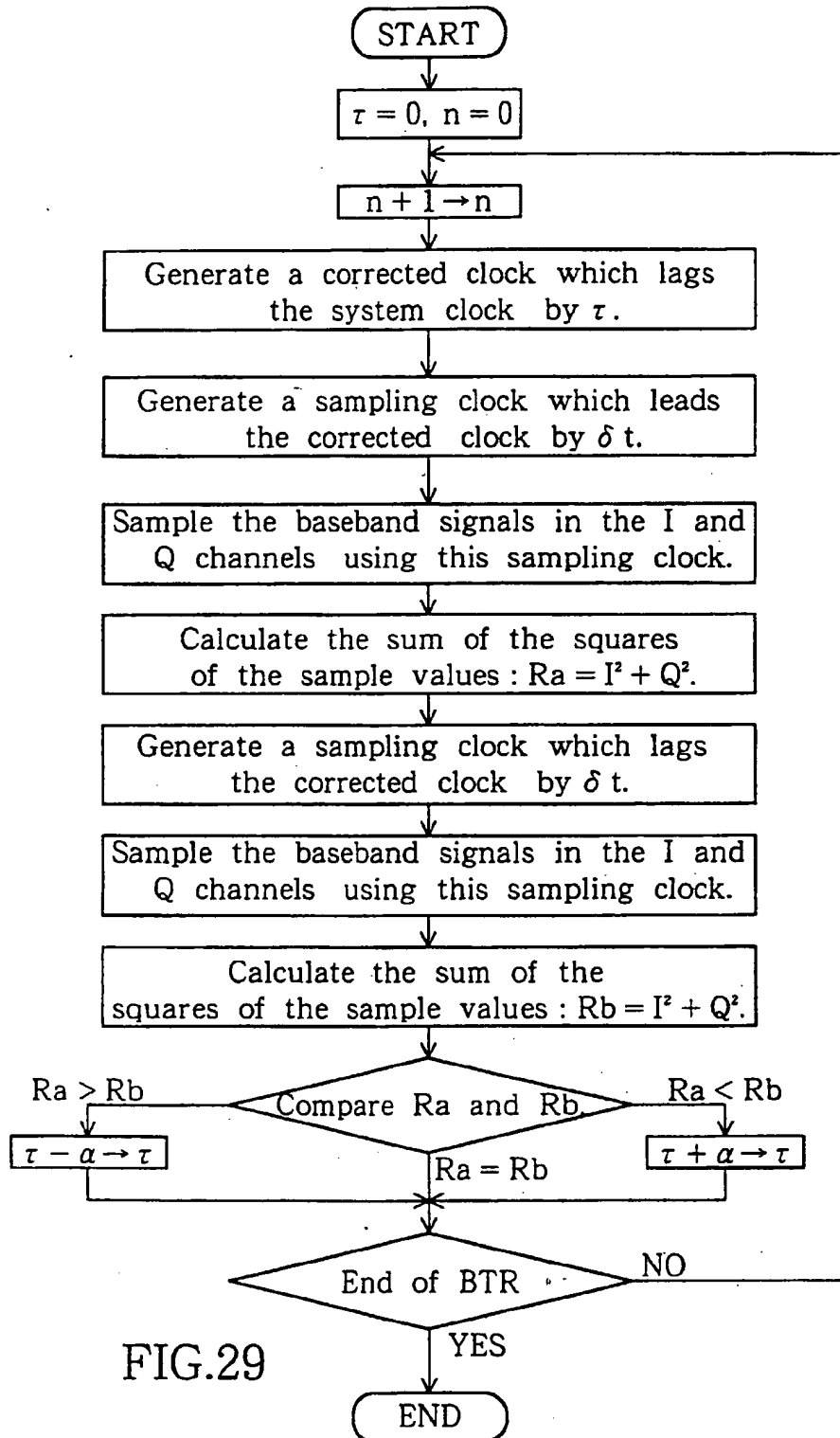
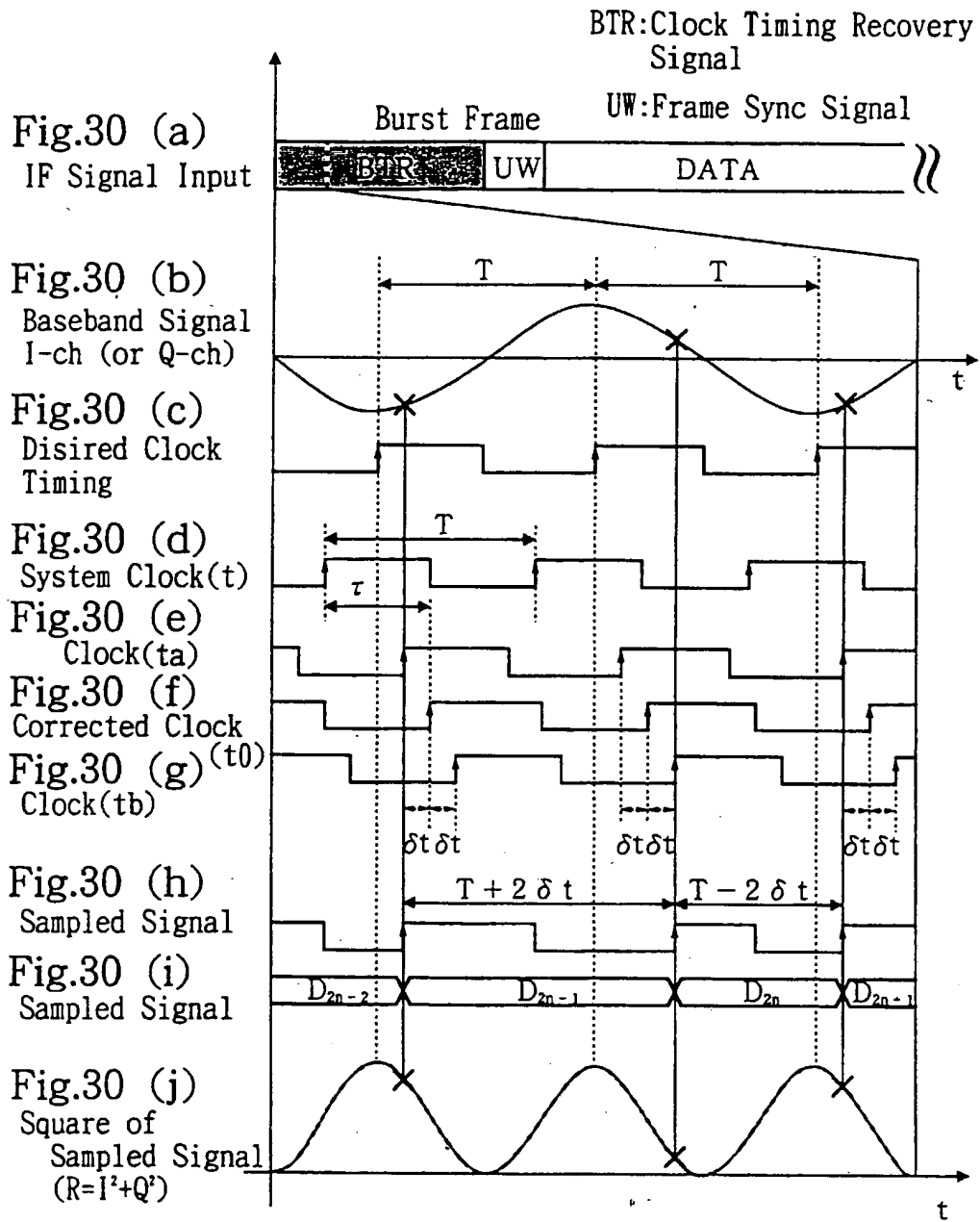


FIG.29



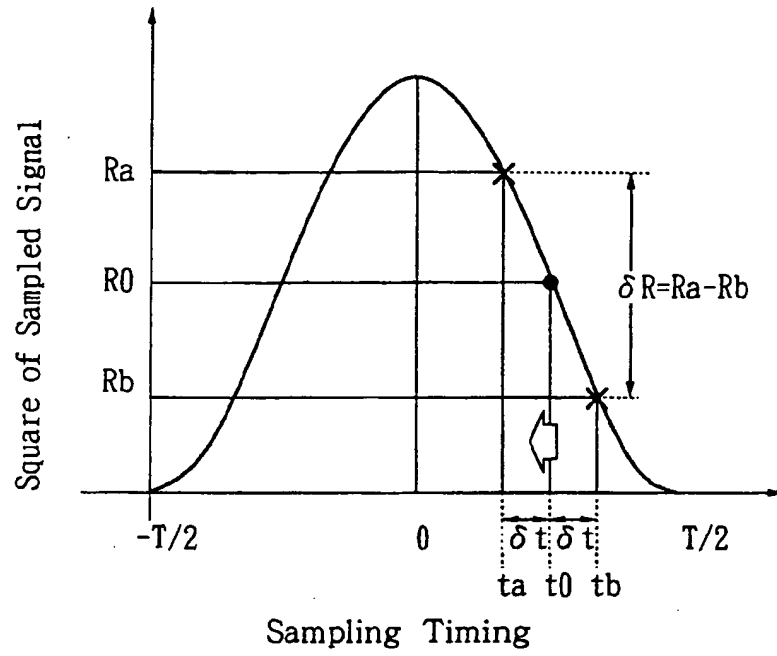


FIG.31

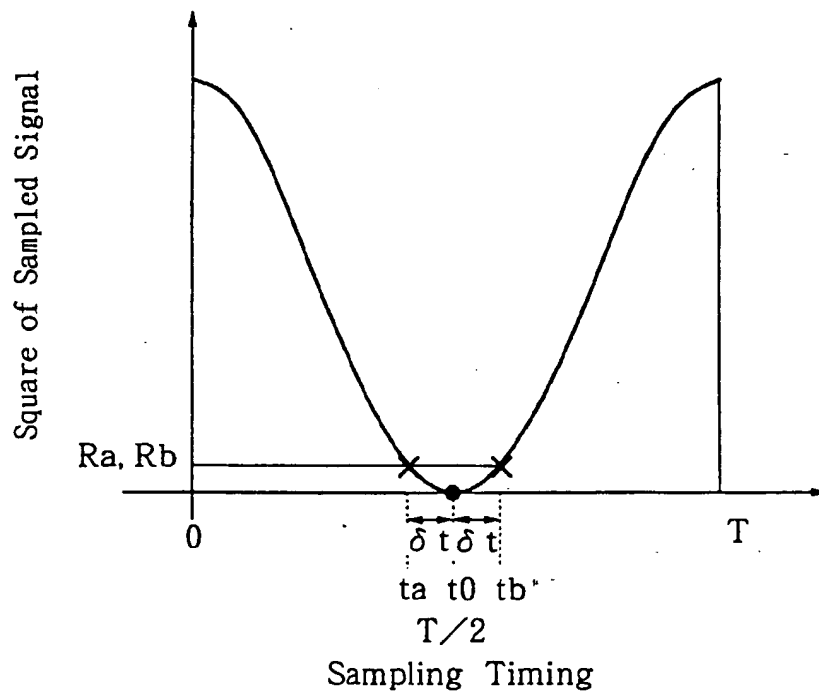


FIG.32

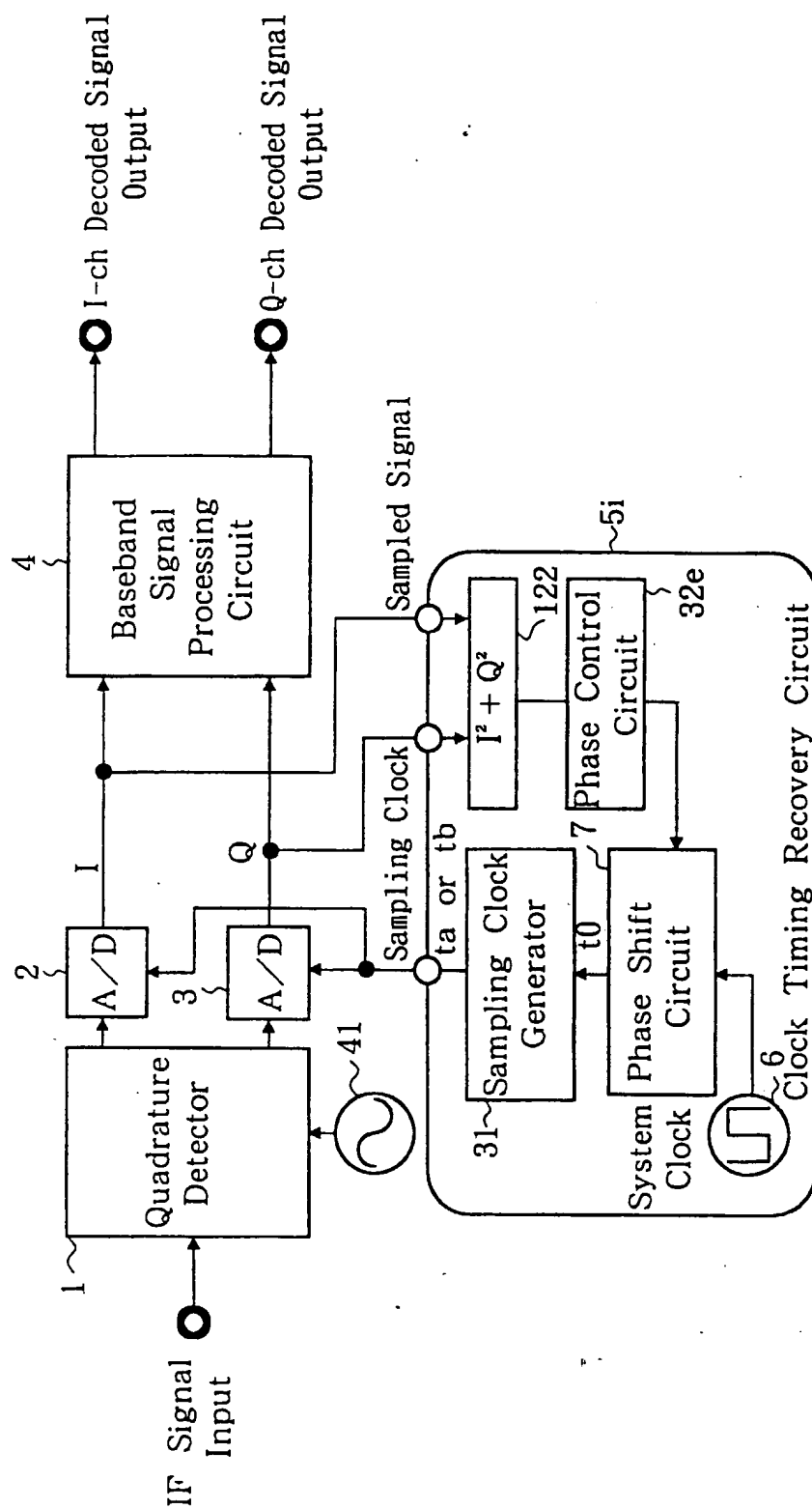


FIG.33

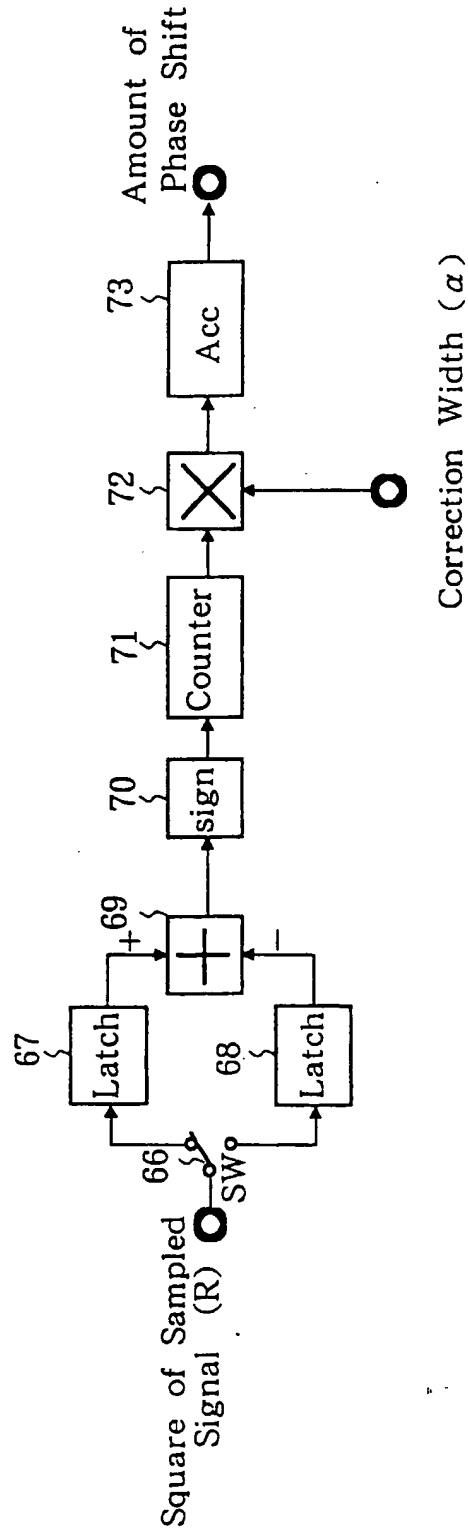


FIG.34

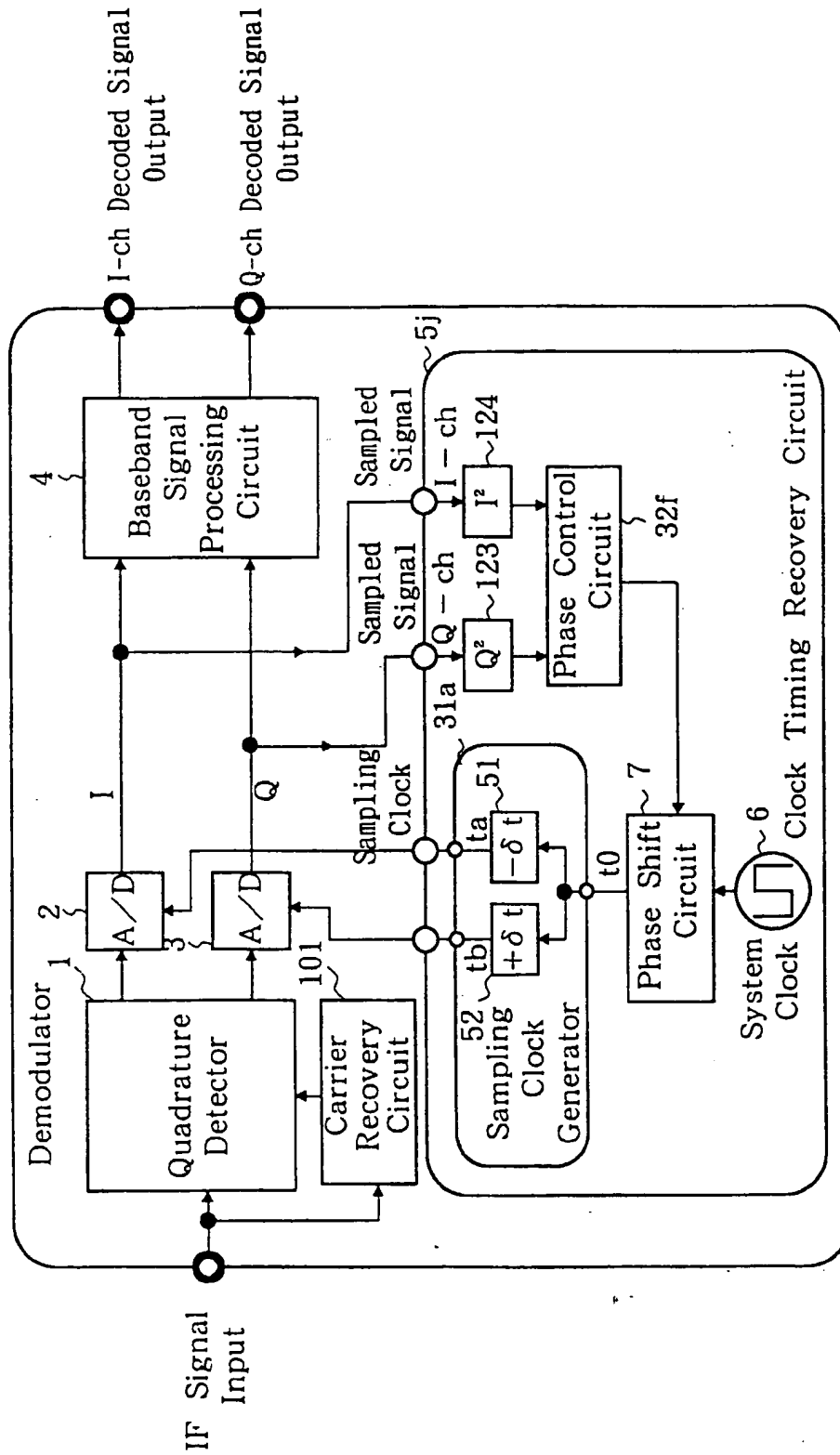


FIG.35

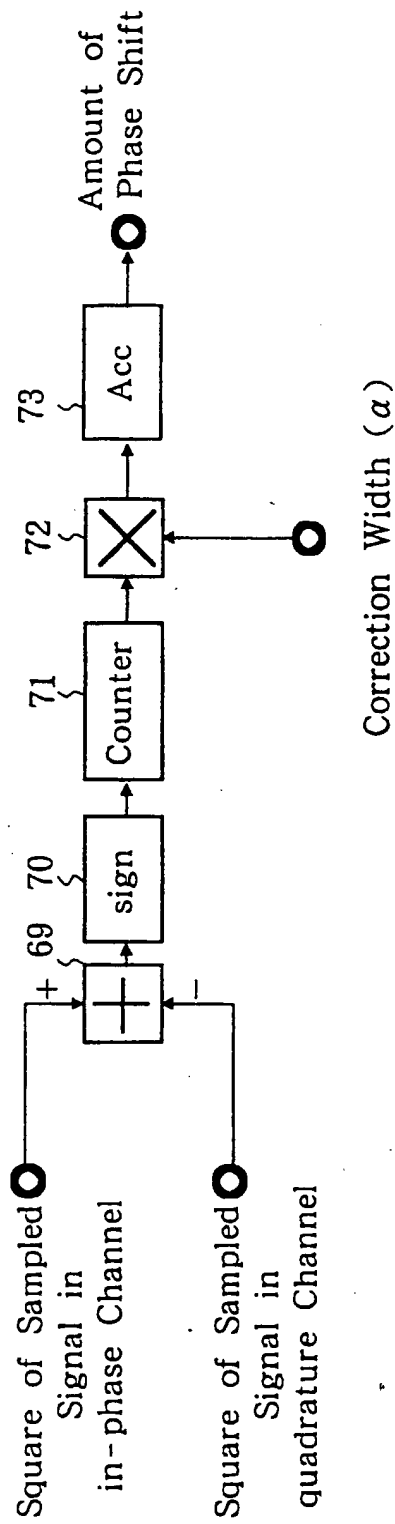


FIG.36

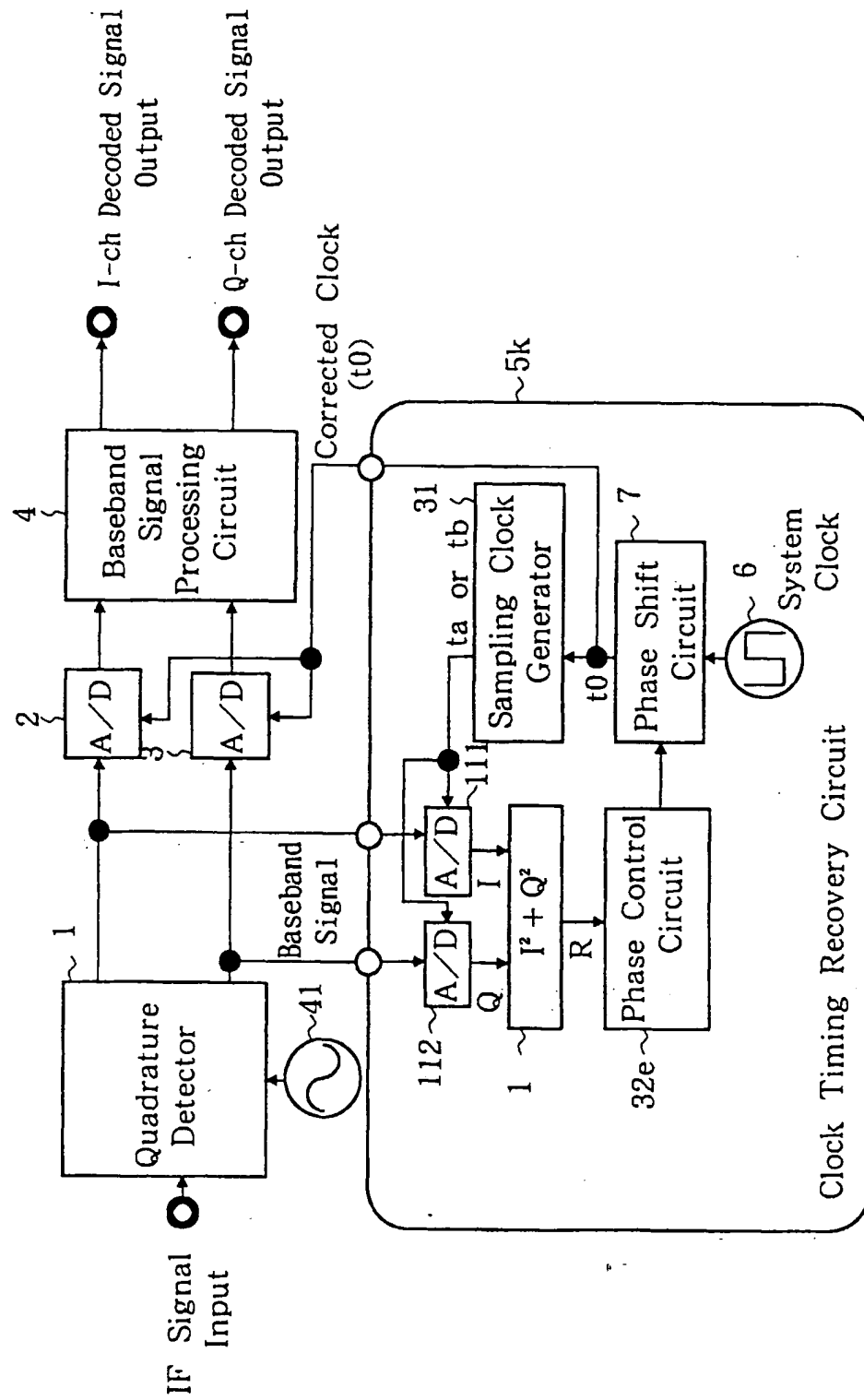


FIG.37

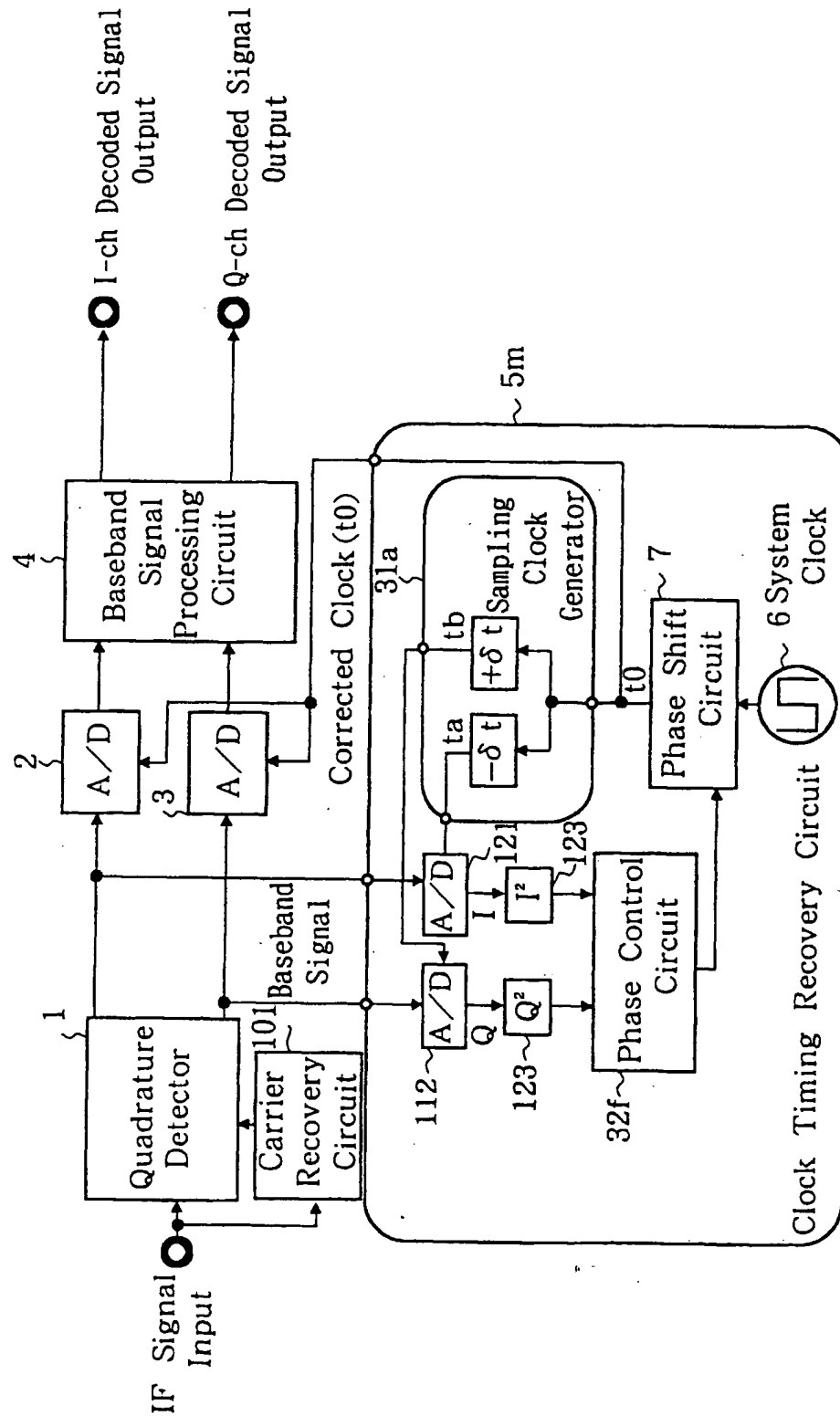


FIG.38

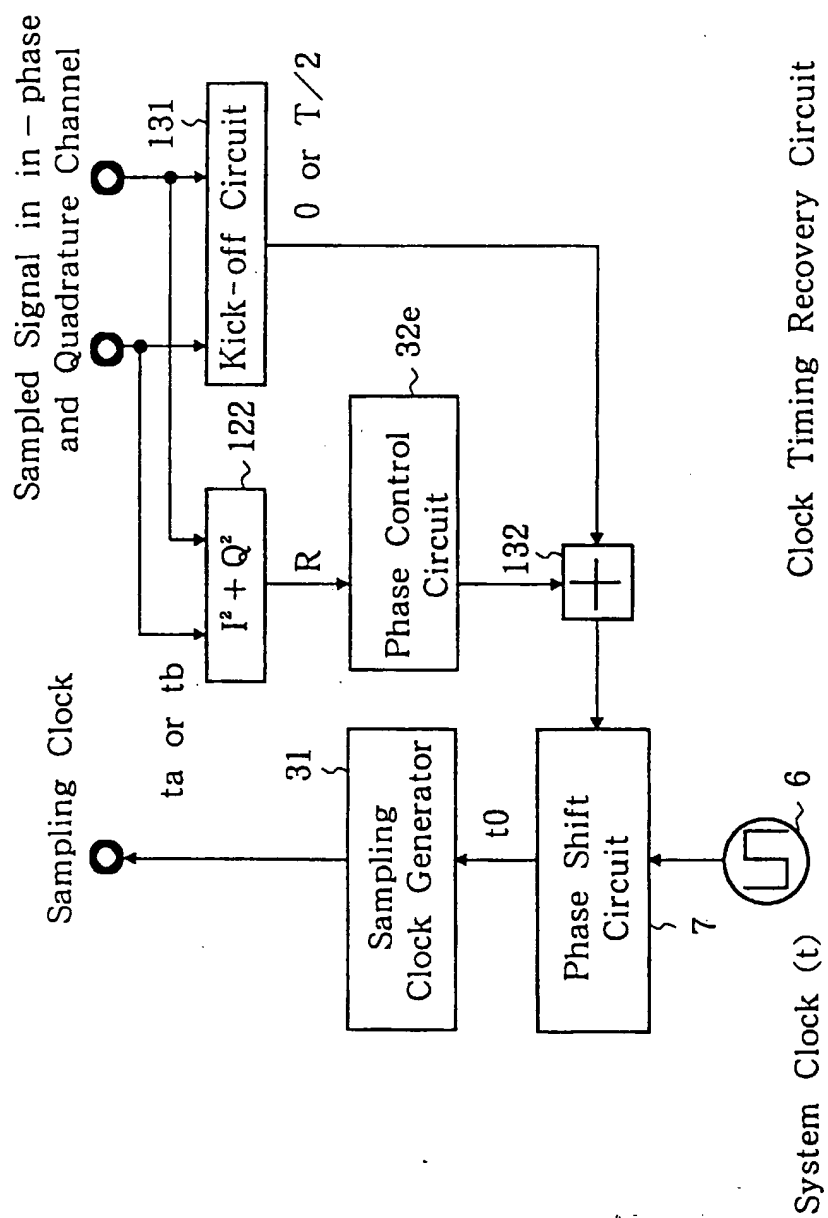


FIG.39

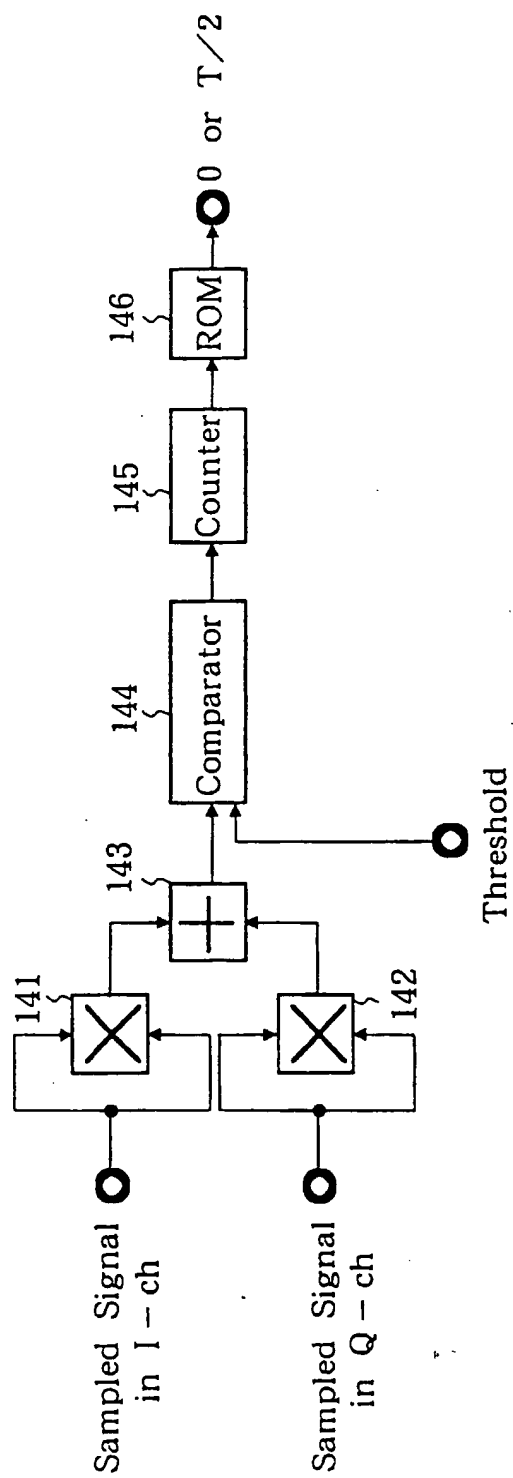


FIG.40

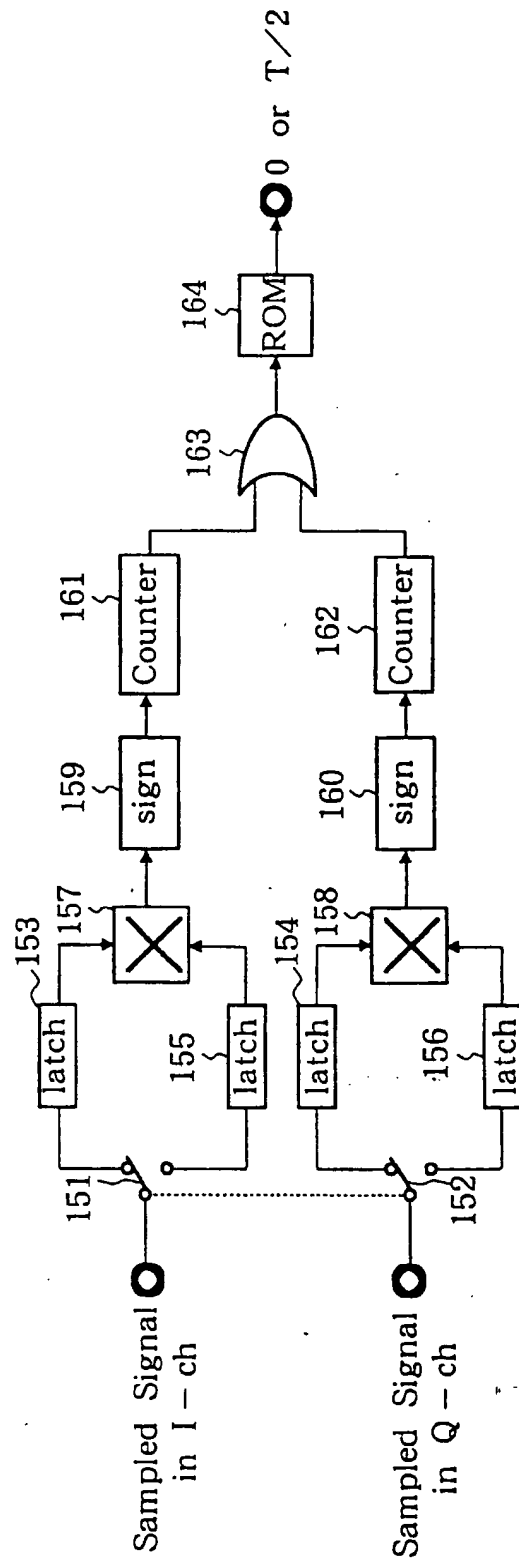


FIG. 41

Fig.42 (a)

Baseband Signal
I-ch (or Q-ch)

Fig.42 (b)

Disired Clock
Timing

Fig.42 (c)

System Clock

Fig.42 (d)

Clock (ta)

Fig.42 (e)

Corrected Clock (to)

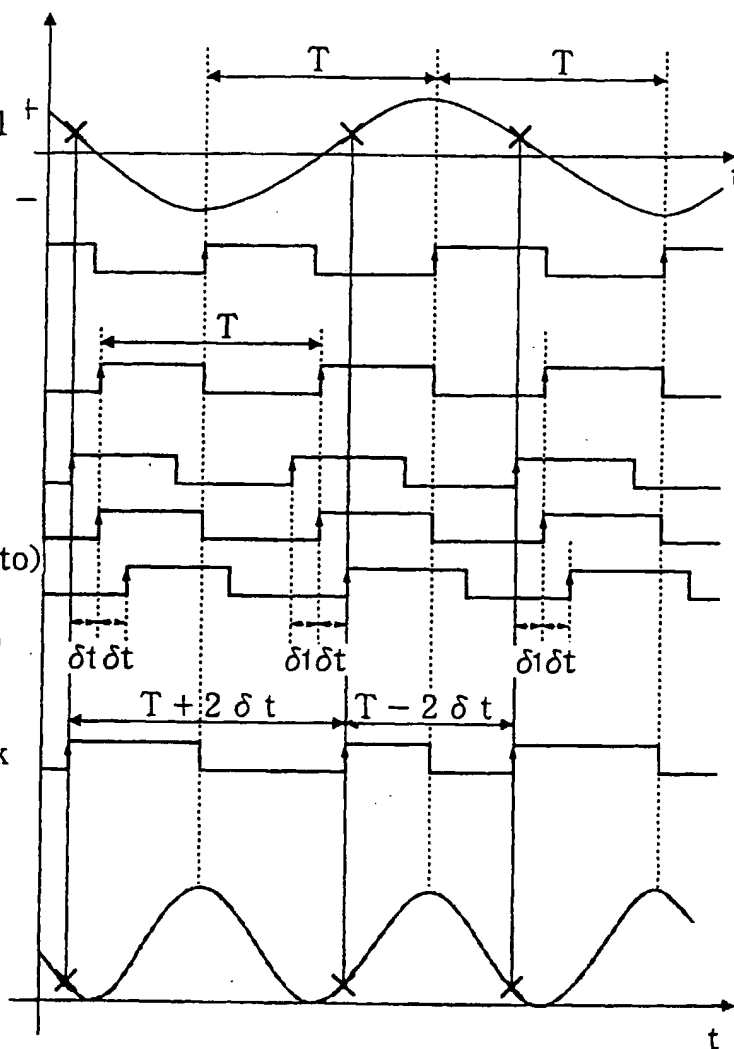
Fig.42 (f)

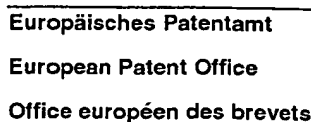
Clock (tb)

Fig.42 (g)

Sampling Clock

Fig.42 (h)

Square of
Sampled Signal
($R=I^2+Q^2$)



(11)

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(71) Applicant: NIPPON TELEGRAPH AND
TELEPHONE CORPORATION
Shinjuku-ku, Tokyo 163-19 (JP)

(72) Inventors:

- Takao, Toshiaki
Yokohama-shi, Kanagawa 236 (JP)
- Suzuki, Yoshifumi
Yokosuka-shi, Kanagawa 238-03 (JP)
- Shirato, Tadashi
Kiyose-shi, Tokyo 204 (JP)

**(74) Representative: Skone James, Robert Edmund
GILL JENNINGS & EVERY
Broadgate House
7 Eldon Street
London EC2M 7LH (GB)**

(54) Clock timing recovery methods and circuits

(57) In a clock timing recovery circuit for recovering the clock timing from a baseband signal obtained by detection of a received signal, clock timing is rapidly established by using a clock which has been phase-shifted from the desired clock timing to sample the baseband

signal, and by obtaining the optimum phase from the sampled signal obtained as a result. A clock-timing recovery circuit according to this invention does not require oversampling and provides easy optimisation of circuit constants.

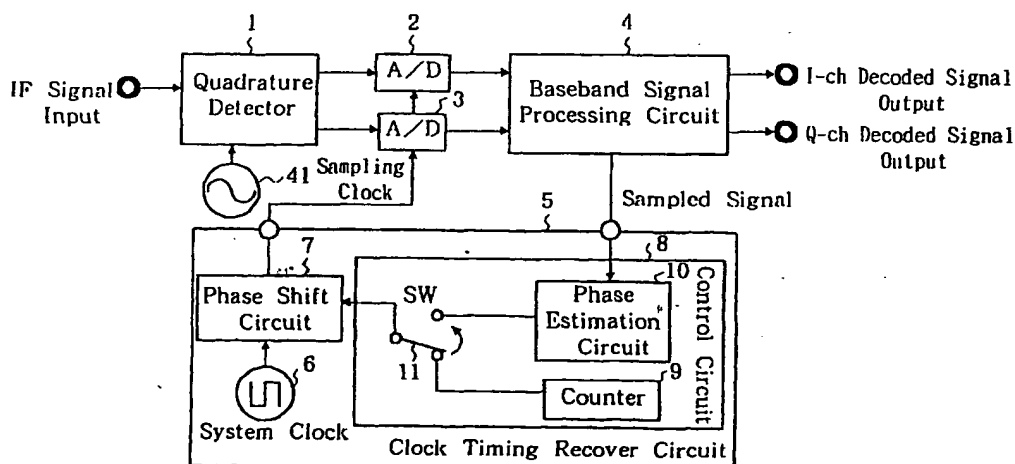


FIG.4



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 5040

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 28 September 1999	Examiner Pieper, T
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document</p> <p>T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons &: member of the same patent family, corresponding document</p>			

EPO FORM 1503 (03/82) (P04001)



European Patent
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Application Number

EP 97 30 5040

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:



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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 28 September 1999	Examiner Pieper, T
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

EPO FORM 1503 (3-92) (P40001)



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**LACK OF UNITY OF INVENTION
SHEET B**

Application Number
EP 97 30 5040

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1, 2, 24

Clock timing recovery circuit sampling a signal for clock timing recovery by a phase shifted sampling clock whereof the N-th phase shift is shifted N-times from an origin point

2. Claims: 3- 23, 25-28

Clock timing recovery circuit using second clock signal, which leads edge points of the first clock, and third clock signal, which lags edge points of the first clock

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 97 30 5040

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